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ORIGINAL ARTICLES

THE GENUS *FUSARIUM*

II. A SPECIES OF *FUSARIUM* AS A CAUSE OF WILT OF GRAM (*CICER ARIETINUM* L.)

BY

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(Received for publication on 23rd December 1938)

(With Plate XVIII)

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I. Introduction

Wilt of gram (*Cicer arietinum*) is a common disease in many parts of India where this important crop is grown on a wide scale. It has been reported as being particularly serious in Madras [Narasimhan, 1929] and has been noted in Bengal [Hedayetullah, 1937]. Although the disease has been known for a long time it has not been extensively studied. Wilted plants were received at Pusa (Bihar) from Burma in 1920, a year in which the crop had been severely damaged. Isolations were made from the wilted plants and species of *Fusarium* were obtained in culture. Attempts to reproduce the disease with these isolates failed [Mitra, 1925] but inoculations with a later isolate were partially successful [McRae, 1932]. It was thought by McKerral [1923] that the disease was soil-borne and could be avoided by long rotations with other crops.

Narasimhan [1929] proved that gram wilt could be caused by a species of *Fusarium*. He described the fungus but did not name it. It is not possible from the description given to name the species with confidence.

In 1935 Dastur reported that wilt had caused serious damage to the gram crops at Nagpur, Central Provinces, and he found that *Fusarium* was associated with almost every wilted plant, but he was unable to prove the pathogenicity of the fungus and considered it to be a saprophyte living in the soil. He also obtained *Rhizoctonia bataticola* (Taub.) Butl. in culture and found that it was responsible for slight damage. However, the true wilt, he concluded, was due to unfavourable soil conditions. By repeatedly sowing the crop in the same place he found that it was affected year after year. While suggesting that wilt was of physiological origin he was not clear as to the exact nature of the ailment.

During the past two seasons (1936-37, 1937-38) the gram plots at the Imperial Agricultural Research Institute at Delhi have suffered death of plants before reaching maturity up to the extent of ninety per cent, and most of the plots have shown at least twenty-five per cent loss. Observations made at the Agricultural Sub-Station at Karnal showed that of the eighty-four types grown almost all showed severe damage. The material for this study was collected at these two centres in 1937 and 1938.

II. Symptoms

The disease was generally observed in the field when the crop was about one month old, and the number of dying plants was usually greatest when they were two or three months old. The plants could be divided into three groups according to the symptoms they produced :—

(1) Those in which the first symptom was drooping of the upper leaves followed soon by the lower leaves. The plants withered and died within about a week.

(2) Those in which the leaves gradually turned yellow and then began to drop, the remaining leaves rapidly withering and the plant dying.

(3) Those in which the leaves became red. In the later stages these plants resembled those of group (2).

The disease was not limited to isolated plants but was found in patches of various sizes in which a high percentage of plants was killed.

When sections were made of the roots and stems of the three different forms of wilted plants all appeared alike. Fungal hyphae were numerous in the vascular tissues of all plants showing typical symptoms of wilting. The number of hyphae in a vessel varied greatly, some vessels containing only a single strand while others were completely filled. In some plants in the last stages of infection the cortex of the roots was heavily invaded by mycelium. The cell-walls of the phloem tissue of infected plants appeared to be considerably thickened and the colour of this tissue was often dark brown.

Hyphae could be seen high up in the stems but were never observed in the petioles of leaves.

III. Isolation

Two methods of isolation were used :—

(*a*) Portions of roots and stems, half to one centimeter in length, were thoroughly washed in water and were immersed in 0·1 per cent mercuric chloride solution for five to ten minutes. They were then transferred aseptically to sterilized water and were washed three or four times in separate lots of water. Finally they were transferred to slopes of oatmeal agar.

(*b*) Similar portions of roots and stems after preliminary washing in water were transferred to a one per cent aqueous solution of silver nitrate. After about two minutes they were removed and immersed in a sterile one per cent solution of sodium chloride to precipitate the disinfectant, according to the method described by Davies [1935], and were transferred as soon as possible to agar slants.

From almost all pieces of infected tissue *Fusarium* grew out in the course of about a week or ten days. There were few other fungi. The isolates of *Fusarium* varied markedly in many characteristics. Since over three hundred isolates of *Fusarium* were obtained many of which appeared alike, it was found necessary to reduce greatly the number for detailed examination. It was found that this could be done rapidly (without the use of a microscope) by grouping them into types, according to the major characteristics, notably the kind of spore-bearing structures and alteration of the colour of the medium. Thirteen such groups were formed, and many members of the various groups were then rapidly examined microscopically to determine whether there were marked differences within the groups. Only slight differences were observed, indicating that the selection based on microscopic characters was fairly reliable for the purpose of reducing the number of isolates for further study. The thirteen types obtained are described briefly in Table I.

Table I

Types of fungi isolated from gram

Type No.	Aerial mycelium	Discoloration of medium	Spore-bearing structures
1	Whitish, abundant	Brown	Sporodochia
2	White, fluffy	None	None
3	Pink	Pink	None
4	Purple	Purple	None
5	Pink	Carmine	None
6	Dark purple	Dark purple	None
7	White	None	Thin layer on surface of agar
8	White, scarce	None	Ditto
9	White	Pink	None
10	White	Pink	Green sporodochia
11	Buff	Pink	None
12	White	Brown	Pale yellow sporodochia
13	Pink	Pink	Slimy mass

In Table II are listed the numbers of isolates of the various types obtained at each date of isolation, together with the source of the material.

TABLE II

Numbers of isolates of each type obtained

Type No.	Number of cultures of isolates made on 4-3-37 (Karnal)	Number of cultures of isolates made on 27-11-37 (Delhi)	Number of cultures of isolates made on 9-12-37 (Karnal)	Number of cultures of isolates made on 18-1-38 (Delhi)	Total number of isolates (Both centres)
1		10		6	16
2		43	5	19	67
3		15		5	20
4		13	28		36
5		10		7	17
6		9			9
7		26		12	38
8		16			16
9	37		10		47
10	15		15		30
11	18				18
12	9			3	12
13	4				4

An effort was made to isolate *Fusarium* from the seeds of wilted plants. After surface-sterilizing with silver nitrate solution and washing with sodium chloride solution, they were plated on potato dextrose agar. No fungous growth was found on these dishes after one month, indicating that the fungus was not internally seed-borne.

IV. INFECTION TESTS

Experiment 1

Inoculum was prepared of types 1—8 by growing them in flasks of 100 grams of paddy moistened with 150 c.c. of water and sterilized by autoclaving at twenty pounds pressure for one hour. Four flasks were prepared of each type. After three weeks, when good growth had taken place (on January 25th, 1938) nine-inch pots were two-thirds filled with sterilized soil,

and on the surface of each was sprinkled half the contents of one flask. Ten gram seeds were placed on this inoculum, the remainder of the inoculum was scattered on the seeds, and the pots were covered with 1½ inches of sterilized soil. Controls were prepared by sowing seeds between layers of sterilized soil and paddy. The pots were removed to a bird-proof shelter and kept watered.

The seedlings emerged through the soil ten days after sowing in the case of the controls and those sown in soil containing inoculum of types 1, 2, 7 and 8, but in the other cases no germination occurred. Thirty-two days after sowing, wilting was observed in some plants inoculated with type 2. First the uppermost leaves drooped, then the wilting spread to the lower leaves. Eventually nearly half of the plants in this series of pots died. Eight days after wilting first appeared with type 2, the plants started to wilt with types 7 and 8, and eventually some plants in these pots also succumbed. The experiment was terminated on March 7th by which time the plants were becoming too large for the pots which contained them. The final figures obtained are given in Table III.

TABLE III

Germination and wilting with isolates of types 1 to 8

Type of isolate	Total number of seedlings	Number of seedlings which eventually wilted	Germination percentage	Wilting percentage
1	39	0	97·5	0
2	30	13	75	43·3
3	0	..	0	..
4	0	..	0	..
5	0	..	0	..
6	0	..	0	..
7	38	6	95	15·8
8	38	5	95	13·2
Control	38	0	95	0

The seeds were dug up from the pots in which no germination had taken place and it was found that they were completely rotten. It is clear from this experiment that the *Fusarium* species studied fall into three groups, non-pathogenic (type 1), wilt-producing (types 2, 7 and 8) and seed rotting (types 3, 4, 5 and 6). Sections made from stems of wilted plants revealed abundant

hyphae in xylem vessels and cortex. Re-isolations made from stems and roots of infected plants showed in all cases only fungi resembling those with which they were inoculated.

Experiment 2

This experiment was performed in a manner similar to the previous one except that instead of using paddy the inoculum was prepared from a sterilized mixture of 190 grams of soil, 10 grams of maize-meal and 60 c.c. of water. The fungi, including all types from 1 to 13 were grown for one month. Eight pots of each type containing six seeds were prepared, 200 grams (dry weight) of inoculum being added to each pot. Four of the pots were daily watered with 200 c.c. of water while the other four received only 100 c.c. The seeds were sown on March 1st, 1938.

Seedlings emerged well in the controls and with types 1, 2, 7, 8 and 12 in about six days ; but in the remaining types germination was very poor, most of the seeds on being dug up were found completely rotten.

Seventeen days after sowing, the pots inoculated with type 2 began to wilt in the low water series, and two days later in the high-water series. Wilting first appeared with types 7 and 8 shortly after type 2. Types 1 and 12 caused no wilting and the plants appeared as healthy as in the controls. The germination and the final figures for wilting with the various isolates in the dry series taken on completion of the experiment on March 25th are given in Table IV. The figures for the wet series are omitted as they were essentially the same as the dry series. Plate XVIII shows pots from the seed-rotting, wilting and control series.

TABLE IV

Germination and wilting with isolates of types 1 to 13 after 25 days

Type of isolate	Total number of seedlings	Number of seedlings which wilted	Germination percentage	Wilting percentage
1	24	0	100·0	0
2	23	23	95·8	100·0
3	4	0	16·7	0
4	2	0	8·3	0
5	1	0	4·2	0
6	0	..	0	..
7	24	9	100·0	37·5
8	22	7	91·7	31·8
9	0	..	0	..
10	4	0	16·7	0
11	0	..	0	..
12	24	0	100·0	0
13	0	..	0	..
Control	24	0	100·0	0

Pots of gram inoculated with seed-rotting (left) and wilt-producing (centre) *Fusaria*. Control pot at right

The results confirm entirely those of the first experiment, and indicate that types 9 to 13 showed no wilting, but all these except number 12 caused severe rotting of seeds, preventing germination.

Experiment 3

In view of the fact that heavy inoculations with certain types of *Fusarium* caused seed-rot it was thought that these when applied in lesser quantities might also produce a wilt. Inoculum of type 4 was therefore prepa red in the usual manner from cornmeal-soil mixture. It was applied to pots of sterilized soil in layers above and below the seed as before, the amounts of inoculum in various series being 200, 100, 50 and 25 grams. After three weeks no germination had taken place in any of the inoculated plots, and the seeds were found rotten in the soil, while the controls had produced healthy seedlings. As f ar as the dilutions went, therefore, they did not result in causing wilt. Further reductions in quantity would be necessary in order to say for certain that the symptoms of wilt cannot be reproduced by these fungi.

V. Morphology of the wilt fungus

Isolates of types 2, 7 and 8, all of which caused wilting, were selected for further study. Cultures of each were made by selecting germinating single spores from dilution plates of plain agar.

The three isolates were grown at a temperature of about 25°C. in tubes of the following media prepared according to the methods of Wollenweber *et al.* [1925] :—

Oat agar.

Potato dextrose agar with two per cent dextrose

Potato dextrose agar with five per cent dextrose

Potato cylinders.

Steamed rice.

Colours of the mycelium were noted and named according to Ridgway [1912] after fourteen days' growth. Measurements of 200 spores were taken after twenty-one days' growth. The colours are recorded in Table V, and lengths of conidia in Table VI. No sporodochia were formed, nor were there any signs of sclerotia. A plectenchymatous layer somewhat resembling a stroma was formed on the surface of the agar tubes, but it is questionable whether this could be called a genuine stroma since it was not a raised, cushion-like spore-bearing structure. There appeared to be a concentration of spores on the surface of the agar media and potato cylinder in the case of type 8 and on two per cent potato dextrose agar with type 7, but it would perhaps be stretching the meaning of the term to refer to this concentration as ' pionnotal '. Terminal and intercallary chlamydospores were produced by type 2 on oatmeal agar and steamed rice, and by type 7 on all five media, but none were produced by type 8.

TABLE V

Colours of types 2, 7 and 8 after 14 days of growth

Kind of medium	Type No. 2		Type No. 7		Type No. 8	
	Aerial mycelium	Plecten-chymatous layer	Aerial mycelium	Plecten-chymatous layer	Aerial mycelium	Plecten-chymatous layer
Oatmeal agar .	White	White	White	White	Lacking	White
Two per cent potato dext-rose agar.	,,	,,	,,	,,	,,	,,
Five per cent potato dext-rose agar.	,,	,,	,,	,,	,,	,,
Potato cylinder	,,	Ochraceous buff	,,	Orange buff	,,	,,
Steamed rice .	,,	,,	,,	,,	,,	,,

TABLE VI

Measurements of 200 spores of the three isolates after 21 days of growth

Type No.	Septation group	Number of spores in group	Range (μ)	Mean (μ)
2	0	200	7—15×2—5	9·9×3·2
	1	0		
	2	0		
	3	0		
7	0	128	6—15×2—5	10·2×3·1
	1	50	14—21×2—4	17·5×2·4
	2	22	19—28×2—5	23·4×3·2
	3	0		
8	0	86	7—15×2—5	11·3×3·2
	1	61	15—21×2—5	18·6×3·4
	2	21	19—30×2—5	26·8×3·2
	3	32	28—64×2—6·5	43·2×3·6

VI. Discussion

The isolations carried out in this incomplete study of the gram wilt disease have been insufficient to establish with any certainty what types of *Fusarium* are generally associated with the disease and the results of the study on standard *Fusarium* media have not been given in sufficient detail to enable a final conclusion to be drawn as to the species of *Fusarium* which caused wilt, and certain rather surprising results have been withheld pending confirmation. Some very important points have emerged, however, and this is a good opportunity to take stock of the situation.

One thing is definitely established. Whether or not a wilt disease of gram may be caused by some physiologic disturbance due to unfavourable soil conditions, as believed by Dastur [1935], it is now proved that it may be caused by *Fusarium* and the work of Narasimhan [1929] is confirmed.

Secondly, it is clear that wilted gram plants may harbour an extraordinarily wide variety of *Fusarium* types, perhaps different species, and these are capable of causing two distinct diseases, a seed-rot and a wilt. This is reminiscent of certain diseases of other legumes, notably peas (*Pisum sativum*) and pigeon-peas (*Cajanus cajans*). The complexity of these diseases has been referred to in recent times by Padwick [1938] and Wollenweber [1938]. In such cases it is necessary to make a careful survey of material from many sources before starting to generalise either about the cause of the disease or about the subsequent control measures. The fact that there are fungi causing a pre-emergence blight and that this is quite distinct from the wilt disease in which there is no reduction at all in stand invites attention to the remark of McKerral [1923] to the effect that in Burma severe cases of disease in gram, when it is grown year after year in the same place, result in failure of the seedlings to emerge through the soil. He also may have been dealing with a complex disease.

Thirdly, it is certain that all the three wilt-producing isolates briefly described, although different in minor respects, notably in septation and length of conidia, nevertheless are alike in major characteristics. The abundance of small conidia—' Kleine Konidien ' of Wollenweber and Reinking [1935] and not true ' microconidia ' of Brown [1928] which are non-septate and not pear-shaped, the presence of intercallary and terminal chlamydospores, and the delicate cell walls, place at least isolates numbered 2 and 7 in the section Elegans, while the absence of sporodochia and of pionnotes (at least of unmistakable pionnotes) and the ratio of length to breadth (12·0 :1) of spores where such exist brings us to the conclusion that all three isolates are of the subsection Orthoceras.

From this point it is useless to speculate further. The basis for the identification of *Fusarium* species of the section Elegans is too much in dispute to attempt to name the three isolates we are studying. We have given above only the barest details of our examination of the isolates and a mass of data is now being accumulated in which other species of the sub-section are being compared with these isolates under varying conditions. According to Nelson,

Coons and Cochran [1937] we would be in our rights in calling the three isolates a new species and it would certainly be easier to name them thus rather than attempt to distinguish them on grounds of morphological differences of doubtful validity. What is required is a fair understanding of the range of variability of the isolates in regard to (*a*) environment and (*b*) strain differences. In the present state of knowledge, in fact, it only appears possible to identify these fungi by comparison under identical conditions with all known species of the sub-section. It is a formidable task but there is no alternative and this work is being undertaken.

VII. Summary

(1) Isolations were made from wilted plants of gram (*Cicer arietinum*) at Delhi and Karnal (Punjab).

(2) Over three hundred isolates of *Fusarium* were obtained and on rough inspection appeared to fall into thirteen types.

(3) Representatives of the thirteen types were tested for pathogenicity by infesting sterilized soil. Eight types caused severe seed-rotting, three caused wilting and two appeared to be non-pathogenic.

(4) Examination of single-spore cultures of the three types which caused wilting revealed that at least two were closely related forms belonging to the sub-section Orthoceras. Their exact relationship to one another is being studied.

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SUGARCANE IN THE PUNJAB, II

BY

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Preface

The authors wish to record their appreciation and acknowledgment of the valuable assistance given by the Deputy Directors of Agriculture and their staff, of the Lyallpur, Montgomery, and Multan circles in carrying out these surveys. They also wish to acknowledge the ready co-operation offered by Major G. V. A. Prideaux, Officer Incharge Military Farms, Okara, and other zamindars in the areas covered by this survey in reserving plots of cane for analysis and in giving other valuable help.

The surveys described in this paper were carried out by Dr. Girdhari Lal and Ch. Fateh Mohammad in the Lyallpur and Sheikhupura districts and L. Jiwan Das Chopra and S. Asghar Ali in the Lahore, Montgomery and Multan districts. Special credit is due to S. Asghar Ali and Ch. Fateh Mohammad for help in the arrangement and computation of the data relating to the large number of analyses carried out.

P. E. Lander,
Ramji Narain

Lyallpur ;
9th December, 1937

Introduction

In 1934 the authors of this paper published Part I of "Sugarcane in the Punjab" [Lander *et al.*, 1935], which gave an account of a survey of the sugarcane in the Gurdaspur, Sialkot (sub-mountainous tracts), Jullundur and Hoshiarpur (central Punjab), and the Karnal and Rohtak districts of the

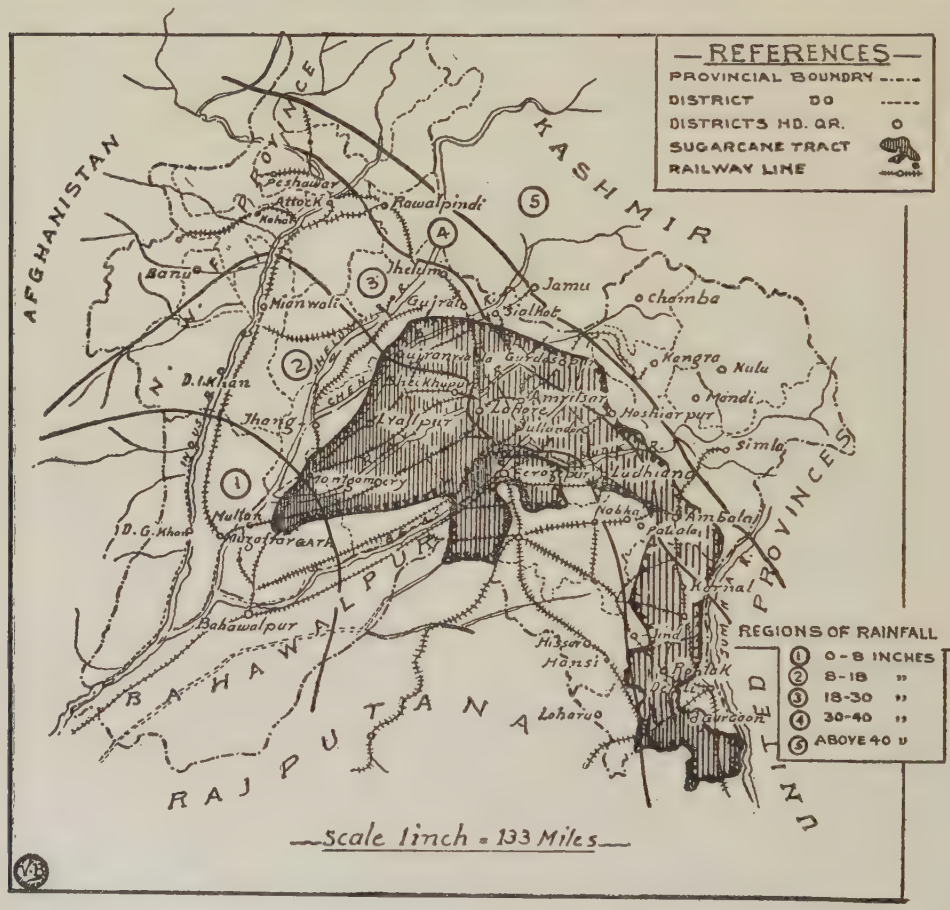

Fig. 1. Map of the Punjab showing main sugarcane tract including districts with an acreage of 10,000 or above, and distribution of average rainfall

south-eastern Punjab. The object of this survey originally was to ascertain those local varieties of sugarcane and the new Coimbatore varieties which would be most suitable for supplying the then increasing number of sugar factories with canes maturing over a period which would ensure an economic working period for the factories. Attention was directed particularly to such aspects as the periods of ripening of the various canes, with tonnage or yield per acre both in stripped cane and juice, the quality of the juice, the effect

of frosts and insect pests and diseases on the juice, and the variations of these and a number of other factors which depended on, or might be influenced by, the geographical situation of the areas surveyed and the prevailing agricultural practices in those areas. The data which was derived from the first survey published in Part I appeared to be sufficiently valuable to justify extending this survey to the Lyallpur, Sheikhupura, Lahore, Montgomery and Multan districts in which very considerable areas are under sugarcane. The present publication gives an account of this survey which was carried on during the cane seasons from 1933-34 to 1936-37, on lines similar to those described in Part I.

Lyallpur District

General physical and climatic conditions

The Lyallpur district lying between latitudes 30°-48′ and 31°-48′, and longitudes 72°-10′ and 73°-48′ constitutes the most important agricultural tract in the new Canal Colonies and includes about 40,000 acres of cultivated land under sugarcane and is thus only second in importance and extent of acreage to Gurdaspur. The annual rainfall is low, being only about 12 to 13 inches per annum, most of which falls in July and August. The soil, fuller particulars of which have been given by the authors elsewhere [Lander, Ramji Narain and Mukand Lal, 1929], consists mostly of medium loam and is inclined to be light and sandy rather than heavy clay and yields high outturns, both in cane and other crops suited to its latitude, with the application of organic manures and also some artificials combined with adequate irrigation. Although so much sugarcane is produced in this district and others of the Punjab, it would be inaccurate to state that the Punjab is particularly suitable for this crop, as in certain districts, of which Lyallpur is one, frost is a regular phenomenon in December and January at a time when its effect on the cane crop is likely to be most adversely felt. The occurrence of frost exercises an unfavourable effect on the general condition of the crop, which effect may be minimised or increased by certain other conditions relating to the current agricultural practices of which the time and extent of irrigation is one.

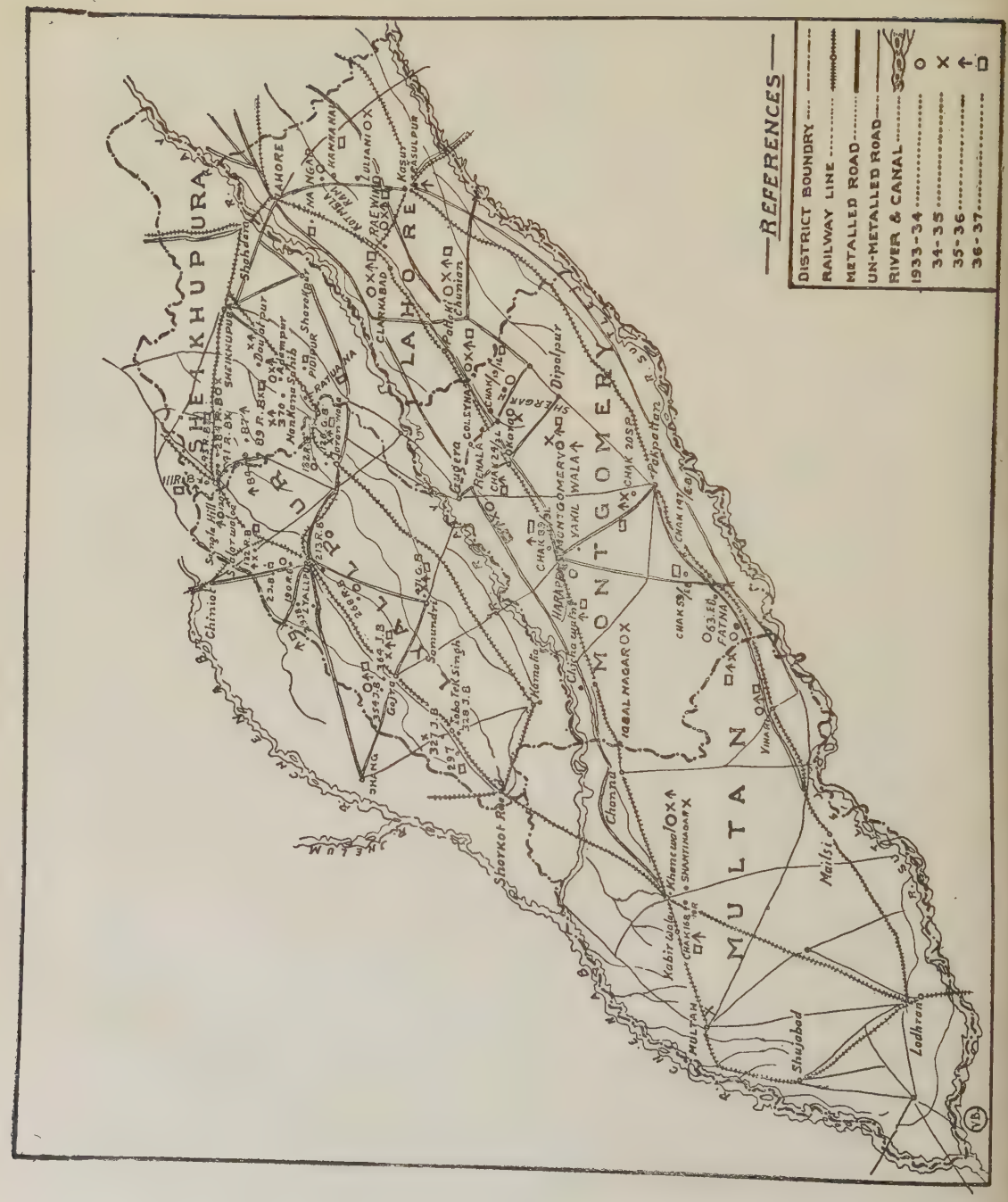

Fig. 2. Map of districts Lyallpur, Sheikhupura, Lahore, Montgomery and Multan showing villages under

Rotations of crops

The rotations most commonly to be found in this district are :—

1. Maize—Sugarcane—Wheat.
2. Maize (*Senji*)—Sugarcane—Wheat.
3. Cotton—Sugarcane—Wheat.
4. Wheat—Fallow—Sugarcane—Cotton.

Farmyard manure is the manure usually applied to sugarcane and the only one which can safely be said to yield an economic return considering the cost of the manure applied. Owing to the very light rainfall in this district the number of irrigations usually given to the sugarcane crop is high, being from fifteen to twenty during the season.

Varieties of sugarcane

Katha, a local variety, is still extensively grown and as late as last season (1936-37) it occupied 86 per cent of the total area under cane in this district.

Katha is a thin cane and gives a low yield averaging about 12·8 tons of stripped cane, 7·42 tons of juice and 1·64 tons of total solids per acre. These figures represent roughly yields of about 2/3rd those obtained from the new Coimbatore varieties. Katha is cultivated in this district more for fodder than for sugar.

Ponda, one of the oldest varieties in the province, is not grown to any considerable extent in the Punjab colonies as, being a thick and juicy cane, it requires a comparatively larger quantity of water for its cultivation and more care than the newer Coimbatore varieties. The most common Coimbatore varieties grown in this district are Co 223 and Co 285, but other Coimbatore varieties which are being introduced are Co 290, Co 312, Co 313 and Co 331. Co 205 was the earliest of the newer varieties to be introduced, but this is now being replaced by others which are superior both in the quality of the juice produced and the tonnage yield per acre, and which have the additional advantage of ripening earlier than Co 205. Another variety, *viz.*, Co 223 is also losing favour with the cultivators as this is a soft cane which has proved to be particularly susceptible to attack by wild animals, insects and various diseases peculiar to cane, and it is also unfavourably affected by frost. The canes which appear to be most suited to the general climatic and other conditions of the Lyallpur district are Co 285, Co 312 and Co 313.

Coimbatore varieties, in addition to being heavy yielding canes, are also suited to the practice of ratooning and on this account are finding increasing favour amongst zamindars.

Period of optimum ripeness

The period of optimum ripeness starting with Katha, the local cane, extends from the 3rd week of November, when harvesting usually begins, to the first week of April, although at certain places the incidence of rain in Decem ber and January may assist in prolonging the crushing season until the las-

week of April. Co 213 is usually the last of the Coimbatore varieties to ripen and becomes fit for crushing about the end of December and remains so until April. Varieties which ripen somewhat earlier than this are Co 223 and Co 285. The introduction of the Coimbatore varieties has considerably extended the period during which the canes of the district are ripe and in suitable condition for factory operations, but this period cannot usually be extended beyond the end of March because by this time the cultivator wishes to prepare his fields for sowing cane and cotton for the coming season and to harvest and thrash his wheat. In order, therefore, to cater for these factors it is necessary to introduce early-ripening canes in the general farming practice in addition to those which are still unripe during the period when frost occurs, *viz.*, from the end of December to the beginning of February, as well as to select varieties which withstand the effects of frost. Speaking generally, analyses of different varieties of cane at present grown in the Lyallpur district show that they are mature and are fit for crushing from the end of November to the middle of April (Table IV).

Two recent Coimbatore varieties which have done well in certain tracts of the Province and also at the Government Farms at Lyallpur and Risalewala are Co 312 and Co 313, but these varieties have not yet been taken up to any extent on zamindari lands. Their more extensive use is however, adovcated as they are high yielders and the analytical data indicate that they are resistent to frost.

Quality of cane

The quality of the juice produced from any particular variety of cane is a most important factor from the point of view of the sugar factory owner. A high quality juice should show high purity values and a low glucose ratio, combined with a low mineral content. Data on the first two of these values are shown in Tables I—III.

Qualitative and quantitative comparison of indigenous and Coimbatore varieties

The relative value of these two types of cane is summarised in averages obtained from the data of the survey in the statement below

Variety	Stripped cane	Juice	Total solids	Sucrose	Glucose ratio	Purity coefficients
			Outturn in tons per acre			
Local . .	12·8	7·42	1·55	1·27	1·7	82
Coimbatore .	18·32	11·76	2·14	1·75	2·8	82
			Outturn per ton of cane			
Local . .	..	0·58	0·121	0·099	..	..
Coimbatore .	..	0·64	0·117	0·096	..	..

This statement shows that Coimbatore varieties are superior in most aspects to the local Katha. The slight difference in the glucose ratio in favour of the local Katha is more than compensated for by the high yield of stripped cane and sucrose from the Coimbatore varieties.

Effect of frost

During the four years of this survey no severe attacks of frost were experienced and therefore it is difficult to say how these new varieties would have withstood frost in the districts surveyed. There was a slight incidence of frost in the 1934-35 season but no extensive ill effects were noted, and in almost all cases recovery was complete. Lander and Ramji Narain [1935] have shown that in the central and southern districts of the Punjab, of the three varieties Co 205, Co 213 and Co 223, Co 213 showed almost complete immunity to frost whilst Co 205 and Co 223 were only slightly affected. It might be expected therefore, that these varieties will respond to frost in a similar way in the districts now being described.

Sheikhupura District

This district, which lies between latitudes 31°-11′ and 32°-4′, and longitudes 73°-16′ and 74°-46′, comprises 2,312 square miles, and adjoins Lyallpur on its south-western side and Lahore on its south-eastern side, was created in 1919 from the districts of Lyallpur, Gujranwala and Lahore. In the last year of the survey, *viz.*, the season 1936-37, this district had about 20,000 acres under sugarcane.

General physical and climatic conditions

The climatic features of the Sheikhupura district more closely resemble those of Lahore and Gujranwala than those of Lyallpur. It receives an annual rainfall of from 15 to 18 inches. Its soil is mostly a medium loam, but owing to the rise of the sub-soil water there is a tendency, at a number of places, for the soil to develop saline conditions or become even alkaline. The normal soil of the district, however, yields a cane crop which for corresponding varieties appears to be distinctly superior to that of the Lyallpur district, a feature which may in some measure be due to the higher rainfall. The general agricultural practice followed is much the same as in the Lyallpur district, and the manurial practices and rotations followed are also similar.

Varieties of cane

Hitherto Katha and Ponda have been the two chief varieties grown, but in recent years the area under improved Coimbatore varieties has been steadily increasing from 15 per cent of the total area under cane in 1932-33 to 32 per cent in 1936-37. This increase of improved varieties in the Sheikhupura district is very pronounced in comparison with the corresponding increase in the Lyallpur district which in the last year of our survey (1936-37 had only 13 per cent of its total cane area under improved varieties. In the Sheikhupura district Katha has given an average of 16 tons of stripped cane per acre and Ponda 28·9 tons. These figures are higher than the corresponding

figures for the Lyallpur district which were 12·8 and 26·2 respectively. The most common Coimbatore varieties grown in the Sheikhupura district during the survey were Co 205, Co 213, Co 223, and Co 285, but during the last two years Co 244 and Co 313 were also introduced. As in the Lyallpur district, Co 205 and Co 223 appear to be losing favour with zamindars, whilst Co 285 is being more extensively developed.

Period of optimum ripeness

The period of optimum ripeness for the local Katha and Coimbatore varieties extends from the 3rd week of November until the middle of April. Of the Coimbatore varieties, Co 313 ripens about two weeks before the local Katha, and during the season of 1936-37 it yielded 70 per cent more stripped cane per acre than Katha. Co 313 remained in a condition fit for crushing until the middle of April, and owing to these favourable qualities it appears to be the most likely variety to replace Katha, hitherto the main cane grown by zamindars in the new Colony areas. Of the other Coimbatore varieties investigated in this district, Co 223 and Co 244 were ripe about the 3rd week of November, whereas Co 213 ripened in the middle of December. It appears therefore that with a judicious combination of the new Coimbatore varieties the cane crushing season can conveniently extend from the beginning of November until the midle of April. The convenience of the zamindar, however, does not as a rule permit him to keep his cane standing in the fields so late in the season (Table VIII).

Quality of the cane

Considering the factors which are involved in the term ' quality ' , Ponda appears to be the best cane of all those examined in this district. Of the Coimbatore varieties, Co 223 and Co 313 (1936-37 only) gave the highest purity figures, but Co 213, Co 244 and Co 285 were almost as good. The main features pertaining to the composition of all these canes are shown in Tables V and VI, whilst the average mean composition and the yields per acre of all varieties examined in the district during the entire period of the survey are given in Table VII.

Comparison of indigenous and Coimbatore varieties

The relative value of these two varieties are summarised in the statement given below :—

Variety	Stripped cane	Juice	Total solids	Sucrose	Glucose ratio	Purity coefficient
			Outturn in tons per acre			
Local . . .	16·0	9·02	1·83	1·50	1·3	82·0
Coimbatore .	22·9	14·84	2·69	2·25	3·0	83·7
			Outturn per tons of cane			
Local . . .	..	0·564	0·114	0·094	..	..
Coimbatore .	..	0·647	0·117	0·098	..	..

From the point of view of sugar and *gur* manufacture (Ponda is mostly used for chewing), the quality of juice of Katha indicates that it is one of the best canes grown, but the above statement shows that the local Coimbatore varieties are equally good and have the additional advantage of yielding about 50 per cent more stripped cane, 75 per cent more juice and 45 per cent more sucrose per acre than Katha.

Lahore District

General and physical conditions

The Lahore district lies between latitudes 30°-38′ and 31°-44′, and longitudes 73°-38′ and 74°-58′, and grows only 5 per cent of the total sugarcane produced in the Punjab. It consequently cannot be regarded as so important a cane-growing tract as are some others. Its importance, however, lies in the fact that it grows Ponda to an extent not found elsewhere. Its climate varies somewhat from that found in the Lyallpur and Montgomery districts, due to its higher rainfall of from 18 to 21 inches per annum, which has the effect of producing somewhat higher average humidity. The Lahore district shows a natural division between the central uplands which include portions of the three tehsils of Chunian, Lahore, and Kasur and the alluvial lands which lie between the Ravi, Sutlej and Beas rivers. These two tracts are respectively designated by the terms 'Sweet Majha' and 'Saline Majha' (Majha Mitha and Majha Khara). In the latter of these as the name implies, the soils and well waters have a tendency to salinity. The rainfall also is a very uncertain factor. These adverse climatic conditions and soil features are mitigated, however, to a considerable extent by canal irrigation. Consequently the agricultural conditions of the district are not disturbed to any great extent. Cane samples concerning which data are given in this paper were taken from both these tracts, although most of them came from the Majha Khara.

Crop rotations

The rotations usually followed are the same as those of the adjoining district of Sheikhupura, except where some modifications are introduced on well-irrigated areas. Heavy applications of farmyard manures are usually applied to Ponda cane in the well-irrigated areas and to a somewhat lesser extent in the canal areas. Maize is the crop in the general rotation which is always heavily manured, although manure is also applied to some extent before sowing sugarcane. The number of irrigations given to the cane crop usually depends here, as elsewhere, on whether it lies in the canal or well-irrigated tracts, and also to some extent on the amount of rainfall. In this district lands which are subject to river action are seldom if ever manured.

Varieties of cane

As already mentioned Ponda is the chief variety grown in this district and is mainly used for chewing, although some *shakkar* is also made from it. Katha and Kahu are the only thin indigenous varieties cultivated. Ponda gave the

highest tonnage of stripped cane and sucrose per acre of all the varieties investigated, the average figures for four years being 28·8 tons and 3·19 tons respectively or about 60 per cent more than was obtained from the Coimbatore varieties. Of the latter, Co 285 appears to be the best, whilst Co 312 which was only introduced in the 1936-37 season gave very poor yields. Other Coimbatore varieties met with were Co 205, Co 223 and Co 290.

Period of optimum ripeness

The harvesting of cane generally begins in the Lahore district about the middle of November, although most of the canes investigated during the survey were not ripe until the end of November. The shortest period of optimum ripeness was noticed in the case of the thick varieties, Ponda and Red Stripped Mauritius, and extended from the beginning of December to the end of March. The longest period extending to more than four months was found with Co 285 and Co 312, but as already remarked Coimbatore canes in this district are not as extensively grown as is Ponda, although there seems to be no reason why they should not do well under careful cultivation. The data in Table XII show that canes in this district are not generally ripe until early December, a fact which may probably be due to the somewhat more moist conditions found here.

Quality of cane

The figures for purity coefficient and glucose ratio of Co 312, although available only for one year, indicate that this variety is one of the most promising in the district, while the same factors show that Co 205 is least satisfactory. The rest of the Coimbatore varieties appear to be of equal merit in this respect (Tables IX and X).

Yields of cane

In computing the yields from the Lahore district during the survey it has been found that some of the Coimbatore varieties exhibit a distinct susceptibility to any curtailment in the water supply. For example it was found, for reasons which we need not enter into here in detail, that canes on the District Board Farm at Raewind suffered from a curtailment in the water supply available in the seasons 1934-35, 1935-36, and 1936-37, with subsequent low yields. Not all varieties suffered equally in this respect, Co 312 and Co 290 being most affected. The above-mentioned fact is illustrated by the figures given in Table XI. If we exclude from our calculations those varieties which suffered from the curtailment of the water supply, then the average figures for yields of the Coimbatore varieties in the Lahore district compared favourably with corresponding figures obtained from the other districts surveyed.

The data for these two groups are shown in the two statements below :

Comparison of indigenous and Coimbatore varieties (excluding Ponda which is not used for sugar making)

*Statement (a)**

Variety	Stripped cane	Juice	Total solids	Sucrose	Glucose ratio	Purity coefficient
			Outturn in tons per acre			
Local . .	8·7	5·14	1·00	0·84	2·9	83·7
Coimbatore .	15·2	9·73	1·76	1·51	3·4	85·9
			Outturn per ton of cane			
Local . .	..	0·59	0·115	0·097	..	..
Coimbatore .	..	0·64	0·116	0·099	..	..

* When the drought-affected canes are included

Statement (b)†

Variety	Stripped cane	Juice	Total solids	Sucrose	Glucose ratio	Purity coefficient
			Outturn in tons per acre			
Local . .	8·7	5·14	1·00	0·84	2·9	83·7
Coimbatore canes excluding Co 290 & Co 312	18·7	11·7	2·09	1·76	4·3	84·4
			Outturn per ton of cane			
Local . .	..	0·59	0·115	0·097	..	..
Coimbatore .	..	0·63	0·112	0·094	..	..

† When the drought-affected canes are omitted

It will be seen that the outturn for the Coimbatore canes is slightly less than double that of the local varieties. It has already been observed that the zamindars of the Lahore district devote most of their energies to the production of Ponda which from their point of view is a more economic proposition as a chewing cane for the neighbouring towns than cane for sugar production.

Montgomery District

General and physical conditions

This district lies approximately between latitudes 29°-58′ and 31°-33′, and longitudes 72°-30′ and 74°-58′, and cannot really be considered a sugarcane growing district of the Province, as it is only within recent years that the cultivation of cane has been taken up to any appreciable extent.

Prior to 1920 the average area under cane in this district was only about 700 acres. From that time there has been a steady increase in the area under cane except during the cotton boom years, 1926-29, when the price of cotton was very high. Since 1930 the area under cane again increased, and in the 1931-32 season, the figure approximated 20,000 acres, after which there was a gradual decline, until, during the period covered by this survey it remained fairly steady between 12 and 15 thousand acres. There are two main divisions in the Montgomery district known as the Ganji Bar and the Nili Bar, respectively. The Ganji Bar which occupies the higher regions of the district was the first to be colonised about the year 1913, whilst the Nili Bar is still being colonised at the present time. Most of the survey work in this district was confined to the Ganji Bar.

The climate of the district taken as a whole is very dry and the mean annual rainfall about ten inches. Temperatures of 120°F. in the shade are common in the summer months, whilst as a contrast the winters are cold, the temperature frequently falling to freezing point and below. The soil of the Montgomery district tends to become lighter as we proceed from the north-east to the south-west, until near the boundary of the Multan district it is extremely light and sandy. The soil between Khanewal and Montgomery is on the whole a very good loam which produces excellent crops, but this area also contains some of the worst and most intractable alkaline lands in the Province, particularly in the Montgomery tehsil of the Ganji Bar tract. A conspicuous feature of this bad soil is a high percentage of sodium carbonate which has converted the normal calcium clay of the soil into a sodium clay.

Although the total amount of clay in the soil is not conspicuously high, yet the soil shows all the features of an excessively hard and impervious clay.

The soils found in the Nili Bar are more uniform in mechanical composition than those in the Ganji Bar and vary from medium loam to light loam as one proceeds from east to west.

Rotations of crops

No definite and fixed rotations are followed by the zamíndars in this district, but generally speaking those which include sugarcane are much the same as are found in the Lyallpur colony. Farmyard manure is almost invariably applied to the cane crop in amounts varying from 400 to 500 maunds per acre. The number of irrigations given is approximately the same *viz.*, between 18 and 20 or perhaps slightly more than in the Lyallpur district.

Varieties of cane

Katha is the most extensively grown local variety, chiefly for fodder purposes, although Ponda is found to some extent mainly in the Depalpur tehsil. The area under local varieties is approximately two-thirds of the total area under cane in the district; the rest is under new Coimbatore varieties and is increasing in extent from year to year. The Coimbatore varieties most usually grown by the zamindars are Co 223, Co 285, and to lesser extent Co 213 and Co 290, whilst Co 205 is being gradually replaced by better varieties. The more recent improved varieties which are at present mostly confined to Government Farms and some large estates are Co 300, Co 301, Co 312 and Co 313. The last named appears to be one of the most suitable and promising canes and might conveniently replace Katha.

Period of optimum ripeness

Katha (period of ripeness 11th November to 10th March) and Co 285 (period of ripeness 28th November to 9th April) are the two canes which ripen earliest of those generally grown by the zamindar. Thus with a combination of these two varieties it should be possible to extend the crushing season from early November to approximately the middle of April. The season might be extended to the middle of April or even longer if Co 300, Co 301 and Co 313, which are generally ripe from the middle of November until the middle of April, and Co 210, Co 213 and Co 270, which are ripe early in December, could be included.

Quality of cane

It will be seen from Tables XIII to XV that the order of yield for stripped cane among the Coimbatore varieties is Co 312, Co 301 and Co 285, and their quality is approximately equal, although Co 301 appears to yield a slightly higher percentage of sucrose on cane. Judging from the percentage of sucrose on cane, Co 313 is the best cane although it yielded only 19·3 tons of stripped cane per acre. Its glucose ratio was also the lowest of all the canes examined. It is interesting to record that, taking averages, the Coimbatore varieties Co 301, Co 312 and Co 313 gave roughly 0·5 tons more sucrose per acre than the older Coimbatore varieties. The figures for Co 285 and Co 223 were 2·08 and 1·80 tons of sucrose per acre respectively.

Comparison of indigenous and Coimbatore varieties

The statement below shows the relative figures in outturn per acre for the local and Coimbatore varieties :—

Variety	Stripped canes	Juice	Total solids	Sucrose	Glucose ratio	Purity coefficient
			Outturn in tons per acre			
Local . .	13·0	7·54	1·60	1·30	1·8	81·5
Coimbatore .	19·1	12·42	2·27	1·93	2·3	85·6
			Outturn per ton of cane			
Local . .	..	0·43	0·123	0·100	..	..
Coimbatore .	..	0·65	0·119	0·101	..	..

Multan district

General and physical conditions

This district lies between latitudes 29°-22′ and 30°-45′, and longitudes 71°-4′ and 72°-55′. It has an excessively hot dry summer extending from April to September with a rainfall of six inches or less per annum, and can hardly be regarded as a suitable tract for the extensive cultivation of cane, which is mainly found in the Khanewal tehsil bordering the Montgomery district. Ponda is grown to some extent near the towns in the Multan tehsil for chewing purposes. The rotations and general agricultural practice followed are much the same as those of the adjoining Montgomery district. Farmyard manure is applied to sugarcane, which in the Khanewal tehsil is almost entirely irrigated by canal water, whilst such cane as is grown in Multan and Shujahabad tehsil is irrigated by well water, the level of which lies about 25 to 30 feet from the surface.

Varieties of cane

After Ponda (the chewing cane), Katha is the most important local variety found, whilst Co 205, Co 223 and Co 285 are the only new varieties found on zamindars' lands. The data recorded in this paper on other varieties were obtained from the Agricultural Farm at Multan, the B. C. G. A. Farm at Khanewal, and the Government Seed Farm at Vihari. It is interesting to record that inspite of the adverse climatic conditions of this district the Coimbatore varieties have given, where irrigation and manuring facilities are adequately available, as high yields as in the Montgomery and Lahore districts

Period of optimum ripeness

During the four years of the survey, Katha was observed to be the earliest cane to ripen, about the middle of November, and remained in a condition fit for crushing until the 2nd week of April. Co 223 and Co 285 were ripe early in December, and Co 205 at the end of December. The other canes tested at the Government Farm at Vihari, *viz.*, Co 290 and Co 312, were ripe before the end of November, and Co 281 and Co 213 early in December. Agricultural requirements, however, rarely permit the cane to remain in the field later than the end of March. (Table XX).

Quality of the cane

The data presented in Tables XVII to XIX, give the figures for yield and composition for the different varieties studied, Co 285 grown under zamindari conditions appears to yield the highest tonnage of stripped cane and sucrose per acre, but its average purity coefficient and glucose ratio were low compared with the other Coimbatore varieties. Of these Co 312 gave the highest yields of stripped cane and sucrose per acre and it may be remarked that this variety did much better at the Agricultural Farm at Vihari in the seasons 1935-36 and 1936-37 than in the previous year at the B. C. G. A. Farm at Khanewal. Generally speaking, almost all the varieties did better at the Vihari Farm than in the Khanewal tehsil.

Comparison of indigenous and Coimbatore varieties

Variety	Stripped cane	Juice	Total solids	Sucrose	Glucose ratio	Purity coefficient
			Outturn in tons per acre			
Local .	14·4	8·18	1·71	1·45	1·1	85·2
Coimbatore .	19·1	12·20	2·19	1·87	2·3	85·3
			Outturn per ton of cane			
Local . .	..	0·57	0·119	0·101	..	..
Coimbatore .	..	0·64	0·115	0·098	..	..

On the whole, the Coimbatore varieties in this district have done better than the local ones, although not so well as in other districts. Katha however appears to have done better in the Multan district than in Montgomery or Lahore.

SUMMARY

1. The survey described in this paper was conducted for four years in the Lyallpur, Sheikhupura, Lahore and Montgomery districts and the Khanewal tehsil of the Multan district.

2. On account of intensive heat in summer and cold winters, more particularly the latter, the Lyallpur and Montgomery districts cannot be regarded as pre-eminently suitable for sugarcane, yet owing to canal irrigation the Lyallpur district which has more than 40,000 acres under cane ranks next to Gurdaspur, the premier cane-growing district of the Province. The data obtained during these surveys indicate that with adequate irrigation there appears to be no reason why cane growing could not be developed in the Montgomery district to the same extent.

3. In the Multan district, which is hotter and more arid than Lyallpur and Montgomery, the absence of irrigation facilities is a more serious limiting factor for cane growing than the high summer temperatures.

4. The hardier varieties which are better able to withstand extremes of temperature and scarcity of water are more suitable than the soft ones for the tracts described in this report.

5. Coimbatore varieties have invariably been found to give better yields of cane and sucrose per acre than the local varieties. The best yields from both local and Coimbatore varieties were obtained in the Sheikhupura district, whilst the yield from local canes in the Multan district (Khanewal) was the next best after Sheikhupura, and slightly better than Montgomery. Both at Montgomery and Multan, Coimbatore canes did equally well as regards yield.

It is interesting to record that the Lahore district, which appears to be one of the most suitable of all the tracts surveyed, gave the lowest yields of indigenous cane of any district in the Punjab, possibly due to the fact that zamindars there pay more attention to thick canes such as Red Striped Mauritius and Ponda varieties which are grown for chewing and fetch better prices. These thick varieties which are extensively grown in the Lyallpur district have been found to give better yields than the Coimbatore varieties. It was found that the greatest amount of sucrose produced from an acre of local cane was obtained in the Multan district, Sheikhupura, Lyallpur and Montgomery coming next in order. The Coimbatore varieties gave the highest yields of sucrose per acre in Sheikhupura and Montgomery. The order in which the various districts have benefited most in respect of increased yields of sucrose per acre due to the introduction of new Coimbatore varieties appears to be Lahore, Sheikhupura, Montgomery, Lyallpur and Multan.

6. The Coimbatore canes, which have been introduced in the Punjab from time to time, have been steadily improving in quality as judged from the figures for sucrose percentage on cane and therefore the cultivators are now more eager to take to Coimbatore varieties than they were before.

7. Owing to very hot summers followed by the dry autumn months, sugarcane in the Lyallpur and Montgomery districts ripens comparatively earlier than in other districts of the Punjab excepting Sheikhupura, where for certain unexplained reasons, the crop is the earliest to ripen.

8. With the introduction of new varieties, the period of optimum ripeness has been considerably increased. In the Sheikhupura district where the canes

mature earlier than elsewhere the crushing season was found to extend over a period of 154 days, while in the Lyallpur, Montgomery, Multan and Lahore, it was 145, 146, 146 and 124 days respectively. The crushing season is considerably longer in these districts than in the central and south-eastern districts, due partly to the introduction of early ripening varieties of which Co 313 is the most important.

9. The districts covered by the present survey were found to be comparatively free from those diseases and pests which usually cause damage to the cane crop in the central and south-eastern districts. The only disease met with was red-rot, which was severe in the Chunian tehsil of the Lahore District and Depalpur of the Montgomery district. Top borer was found to cause serious trouble at the Montgomery, Fatna and Vihari farms. Both red-rot and top borer are at present localised and all possible efforts should be made to prevent their extension.

General observations on sugarcane in the Punjab

It might be of interest now to consider the figures for average outturn of stripped cane per acre and the amount of sucrose contained therein for the different cane-growing districts of the Punjab which have been considered in this paper and in Part I.

Table XXI below shows that the Rohtak and Karnal districts in the south-east of the Punjab have hitherto given the highest yields of stripped cane per acre both for local and Coimbatore varieties. The Jullundur and Hoshiarpur districts come next in order of yield. Of the remaining districts dealt with in these surveys the Lahore, Gurdaspur, and Sialkot districts have given the lowest yields of local canes, while the Lyallpur, Montgomery, Multan and Sheikhupura districts occupied an intermediate position in the order given.

The yields of the Coimbatore canes from the Sheikhupura district were approximately the same as for the corresponding varieties from Jullundur, whilst the remaining districts yielded about 19 tons of stripped cane per acre in each case. These figures indicate that the introduction of new Coimbatore varieties has been very profitable for those districts which have hitherto produced only low yields of local cane. The figures for the yields of sucrose per acre follow approximately the same order as those for stripped cane. It may be noted, however, that although less sucrose was obtained from the local canes in the Jullundur and Hoshiarpur districts than from those at Rohtak and Karnal, yet the two former districts gave the highest yields of sucrose per acre from the new Coimbatore varieties of any district in the Province. In other words, both the quantitative yields and the quality of the local varieties in the Rohtak and Karnal districts were superior to the local varieties in other tracts of the Province, and the Coimbatore varieties in the Gurdaspur and Lahore districts were superior to the local varieties both in tonnage yield and in quality.

It will be seen from Table XXIII that Gurdaspur had the largest area under sugarcane, Lyallpur coming next, Sialkot being second however in 1936-37. As already recorded, however, the Montgomery district has not hitherto been regarded as a suitable cane growing tract owing to high summer temperatures and some other unsuitable features. Although Lyallpur experiences approximately the same climatic conditions as Montgomery, yet the yields from both local and Coimbatore canes were better in Montgomery than in Lyallpur. There would appear, therefore, to be no valid arguments against the further extension of cane cultivation in the Montgomery district provided irrigation facilities and manure are available to the same extent as in Lyallpur.

An important matter which deserves close attention but upon which no extensive investigations have yet been carried out, concerns the influence of the nature of and the form in which the alkali bases occur in the soil, on the quality of cane in the Lyallpur, Montgomery, and other districts of the North-West dry area of the Province. The amount of exchangeable calcium present in the soil seems to exercise a great influence on the amount of mineral matter present in the juice. Data available at present indicate that owing to the low concentration of exchangeable calcium in the soil of these districts the juice of the canes gives an abnormally high mineral content which results in a decrease of approximately 10 per cent in the possible recovery of white sugar, compared with a corresponding recovery from the juice of the canes grown in the central tracts of the Punjab. Investigations on this problem have been in progress for some time and the results thereof will be published in due course, when it is hoped that some knowledge may be obtained of methods which may help to alleviate this defect in the canes in question.

Table XXII gives the periods of ripeness and length of the crushing seasons. Corresponding figures for the districts previously surveyed have also been included in this table. It is interesting to note that in every year of this survey almost all varieties of cane in the Sheikhupura district for some obscure reason, ripened earlier than elsewhere. Katha, generally ripens in the Punjab about the middle of November although in the Lahore district it is usually somewhat later. Ponda is usually ripe by the beginning of December. Of the four chief Coimbatore varieties grown in the Punjab *viz.*, Co 205, Co 213, Co 223 and Co 285, Co 205 usually ripen in early December in the western districts of the Punjab but not until early January in the central and eastern districts or even as late as the first week of February in Jullundur. Both Co 213 and Co 223 are ready by early December in the western districts, and by mid-January in the central and south-eastern parts of the Province. Correspondingly Co 285 is usually ready for crushing by the end of November in the western district and mid-January in the central. Considering the cane crop as a whole in the various districts of the Punjab, Sheikhupura, as already noted, stands first as regards early maturity of its cane which is usually ready by the 3rd week of November. Lyallpur and Montgomery follow roughly a week later, whilst Multan and Lahore districts show a still further delay of about one week. In the sub-mountainous regions represented by Gurdaspur

and Sialkot, and the central districts such as Jullundur, Hoshiarpur and the south-eastern districts around Rohtak and Karnal, Coimbatore canes as a whole are rarely ready for crushing before early January.

Length of crushing season

The length of the crushing season for factory or other requirements is obviously governed in the various districts by the periods over which the cane is in a ripe condition. An interesting fact brought out by the surveys recorded in Part I was that, although cane grown under zamindari conditions in the south-eastern districts of the Province gave higher tonnage yields than elsewhere, none of the varieties examined gave a crushing period of more than 100 days. The surveys of the districts recorded in this paper, however, show that in these there is a much wider choice of varieties extending over a longer crushing seasons so that it should be possible to depend entirely upon Coimbatore varieties to supply cane to the factory from the 3rd week of November until the middle of April, whereas in the sub-mountainous districts of Gurdaspur and Sialkot, the central districts of Jullundur and Hoshiarpur and the south-eastern districts of Rohtak and Karnal, it is necessary to depend upon low yielding indigenous early ripening varieties to permit a factory to operate till the Coimbatore varieties become available.

At the Agricultural Farm, Montgomery, the newly introduced Co 300, Co 301 and Co 313 permit a crushing season of more than 140 days, whilst in the Sheikhupura district Co 313 remained in a condition fit for crushing for 154 days. Considering the quality, tonnage, and length of crushing season provided by Co 313 this variety appears to be the most promising one for the districts considered in the present survey, and it is desirable to develop its cultivation more extensively in some of the tracts reported on in Part I to see if its favourable features would be maintained there also. Other varieties which appear to be most suitable for the tracts now reported on are Co 285 and Co 312.

Sugarcane as fodder

It is remarkable that Katha still occupies a very large portion of the total area under cane in the province particularly in the Lyallpur and Sheikhupura districts. The common belief of the zamindars that, in case of scarcity of fodder, this cane can be used as a substitute seems to be mainly responsible for its retention as it yields only about half the tonnage obtained from improved Coimbatore varieties otherwise it might have disappeared long ago. Another reason which zamindars sometimes advance is that Katha ripens much earlier and therefore the *gur* prepared from it in the early season can be sold at a premium. With the introduction of new fodders and new varieties of sugarcane both these reasons have lost their force. For winter berseem is a very good fodder crop and if systematic efforts are made to popularise this crop there is no reason why zamindars should grow Katha rather than the Coimbatore canes. In Co 313 which ripens as early as Katha and yields about three times as much, we have a cane which is an excellent substitute for Katha. It is essential therefore that systematic propaganda in favour

of new Coimbatore varieties should be carried out especially in the Lyallpur district which unfortunately has only about 13 per cent of its sugarcane area under new varieties.

Diseases and pests

The districts surveyed in this report were found to be comparatively free from those diseases and insect pests which usually cause such havoc in the central and south-eastern districts of the Province. The only disease which was found to any extent was red-rot which caused considerable damage to Co 213 and to a lesser extent to Co 223 in the 1933-34 season. In that year it was found to some extent in the Lyallpur and Sheikhupura districts, but was particularly severe in the Chunian Tehsil of the Lahore district where the crop was almost entirely destroyed in some of the fields preserved. In Chunian and in the Depalpur tehsils of Montgomery, red-rot has been steadily increasing in recent years and unless special efforts are made to control it by sowing sound healthy canes, and in cases where the disease has been very severe by burning the diseased crop, it is possible that the trouble may spread further.

Top borer caused serious though localised trouble in the Lahore and Montgomery districts where Co 223 and Co 312 were badly attacked at the Montgomery, Fatna and Vihari farms. As this pest is at present fairly localised, all possible efforts should be made to prevent its extension.

Ratooning

Ratooning is not practised in the districts under report to anything like the extent found in the sub-mountainous and central districts of the Province, but only as a rule in those localities where water is available at a nominal or no cost, such as the riverain tracts found in the Gurdaspur and Hoshiarpur districts. It was very seldom that ratoon crops more than one year old were found in the districts under report, although a feature of such crops is that they usually ripen from a fortnight to a month earlier than the planted crop of the same variety. As remarked in Part I, if the practice of ratooning is adopted, adequate measures of insect control must be carried out.

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TABLE I

Average composition of different varieties of sugarcane during period of maturity (Lyallpur District)

Year	Locality	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
			Juice	Total solids	Sucrose	Glucose		
			Co 205					
1934-35	Chak 132 R. B.	1·35	61·8	10·80	8·20	0·65	7·9	76
1935-36	Chak 471 G. B.	16·00	57·0	10·80	8·83	0·25	2·8	82
1936-37	Chak 328 J. B.	17·20	61·5	11·15	9·13	0·37	4·1	82
Average for 3 years	..	15·85	60·1	10·92	8·72	0·42	4·8	80
			Co 213					
1933-34	Chak 213 R. B.	15·6	66·6	11·50	9·40	0·24	2·7	82
			Co 223					
1933-34	Chak 190 R. B.	18·82	63·9	11·60	9·60	0·40	4·2	83
1934-35	Chak 132 R. B.	16·70	66·3	11·63	9·58	0·31	3·2	82
1935-36	Chak 364 J. B.	15·10	63·7	12·00	10·13	0·28	2·8	84
1936-37	Chak 2 J. B.	23·60	66·4	11·91	10·00	0·30	3·0	84
Average for 4 years	..	18·55	65·1	11·71	9·82	0·32	3·3	83

TABLE I—*contd.*

Year	Locality	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
			Juice	Total solids	Sucrose	Glucose		
			Co 285					
1933-34	Chak 213 R. B.	31·2	62·0	12·30	9·80	0·17	1·7	80
1934-35	Chak 132 R. B.	17·5	64·1	12·18	9·60	0·18	1·8	81
1935-36	Chak 471 G. B.	16·3	60·5	11·70	9·60	0·18	1·9	82
1936-37	Chak 471 G. B.	21·7	62·3	11·80	9·81	0·20	2·0	83
Average for 4 years	..	21·7	62·2	12·00	9·70	0·18	1·9	81
			Co 290					
1934-35	Chak 327 J. B.	19·9	66·6	12·32	10·20	0·20	2·0	83
			Ponda					
1935-36	Chak 126 G. B.	26·2	69·8	13·5	11·68	0·35	3·0	87
			Katha					
1933-34	Chak 190 R. B.	13·7	54·9	11·20	9·30	0·06	0·7	83
1934-35	Chak 132 R. B.	10·8	60·6	12·50	9·93	0·29	2·9	79
1935-36	Chak 132 R. B.	10·7	57·7	12·52	10·22	0·16	1·6	82
1936-37	Chak 126 G. B.	16·1	57·8	12·18	10·28	0·16	1·6	84
Average	..	12·8	57·8	12·10	9·92	0·17	1·7	82

TABLE II

Amount of juice and sucrose, etc., per acre (in tons) and per ton of cane (Lyallpur District)

Variety	Year	Weight per acre				Weight per ton of cane		
		Stripped canes	Juice	Total solids	Sucrose	Juice	Total solids	Sucrose
Co 205	1934-35	14·4	8·90	1·60	1·20	0·62	0·108	0·082
	1935-36	16·0	9·12	1·41	1·73	0·57	0·108	0·088
	1936-37	17·2	10·67	1·91	1·57	0·62	0·112	0·091
	Average	15·9	9·51	1·64	1·50	0·60	0·109	0·087
Co 223	1933-34	18·8	12·04	1·75	1·47	0·64	0·116	0·096
	1934-35	16·7	11·02	1·95	1·61	0·66	0·116	0·096
	1935-36	15·1	9·66	1·81	1·52	0·64	0·120	0·101
	1936-37	23·6	15·58	2·81	2·37	0·66	0·119	0·100
	Average	18·6	12·06	2·08	1·74	0·65	0·118	0·098
Co 213	1933-34	15·6	10·45	1·72	1·42	0·67	0·115	0·094
Co 285	1933-34	31·2	19·34	2·75	2·26	0·62	0·123	0·098
	1934-35	17·5	11·2	2·10	1·70	0·64	0·122	0·096
	1935-36	16·3	9·94	1·90	1·59	0·61	0·117	0·096
	1936-37	21·7	13·45	2·56	2·12	0·62	0·118	0·098
	Average	21·7	13·45	2·33	1·92	0·62	0·120	0·097
Co 290	1934-35	19·9	13·33	2·40	2·04	0·67	0·123	0·102
Ponda	1935-36	26·2	18·34	3·54	3·02	0·70	0·135	0·117
Katha	1933-34	13·7	7·53	1·85	1·52	0·55	0·112	0·093
	1934-35	10·8	6·59	1·41	1·13	0·61	0·125	0·099
	1935-36	10·7	6·21	1·34	1·10	0·58	0·125	0·102
	1936-37	16·1	9·34	1·95	1·64	0·58	0·122	0·103
	Average	12·8	7·42	1·64	1·35	0·58	0·121	0·099

TABLE III

Composition of juice from different varieties of cane—average of four years (Lyallpur District)

Variety of cane	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
		Juice	Total solids	Sucrose	Glucose		
Co 205 . .	15·85	61·1	10·92	8·72	0·42	4·8	80
Co 213 . .	15·6	66·6	11·50	9·40	0·24	2·6	82
Co 223 . .	18·55	65·1	11·79	9·82	0·32	3·6	83
Co 285 . .	21·7	62·2	12·00	9·70	0·18	1·9	81
Co 290 . .	19·9	66·6	12·32	10·20	0·20	2·0	83
Coimbatore (Average)	18·33	64·3	11·71	9·57	0·27	2·8	82
Ponda (Average) .	26·2	69·8	13·5	11·68	0·35	3·0	87
Katha (Average) .	12·8	57·8	12·10	9·92	0·17	1·7	82

TABLE IV

Period of ripeness for different varieties of cane (Lyallpur District)

Year	Varieties of canes						
	Katha	Ponda	Co 205	Co 213	Co 223	Co 285	Co 290
1934-35 . .	26/11 to 10/4	..	20/12 to 4/4	..	27/11 to 25/3	14/12 to 8/4	2/12 to 24/3
1935-36 . .	14/11 to 2/4	30/11 to 12/3	23/11 to 28/3	..	6/12 to 8/4	9/12 to 6/4	..
1936-37 . .	8/11 to 11/4	..	19/11 to 26/3	..	16/11 to 12/4	14/11 to 12/4	16/11 to 12/4
Average period of optimum ripeness	16/11 to 8/4	30/11 to 12/3	1/12 to 30/3	..	26/11 to 5/4	2/12 to 9/4	24/11 to 3/4

N.B.—The figures for 1933-34 are not included as they were abnormal.

TABLE V

Average composition of different varieties of sugarcane during maturity period (Sheikhupura District)

Variety	Year	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
			Juice	Total solids	Sucrose	Glucose		
Co 213 .	1933-34	14·8	64·5	11·50	9·40	0·23	2·5	81
	1934-35	18·1	67·2	11·93	9·90	0·16	1·6	83
	1935-36	23·3	64·9	12·10	9·96	0·14	1·4	83
	1936-37	28·5	67·5	12·80	10·73	0·21	2·0	84
	Average	21·2	66·0	12·08	10·00	0·19	1·9	83
Co 205 .	1934-35	13·3	61·4	10·90	8·34	0·55	6·6	77
	1935-36	26·4	59·2	10·20	8·12	0·51	6·3	79
	1936-37	24·3	62·6	11·26	9·33	0·52	5·6	83
	Average	21·3	61·1	10·79	8·60	0·53	6·2	80
Co 223 .	1933-34	14·9	63·9	11·10	9·33	0·37	4·0	84
	1934-35	15·4	66·5	11·48	9·28	0·41	4·4	87
	1935-36	24·8	64·2	11·72	9·72	0·24	2·9	83
	1936-37	22·8	66·9	11·80	10·17	0·32	3·2	85
	Average	19·5	65·4	11·50	9·63	0·35	3·6	84
Co 285 .	1933-34	23·9	61·8	11·35	9·25	0·22	2·4	82
	1934-35	15·9	63·7	11·36	9·19	0·27	2·9	81
	1935-36	21·8	61·8	11·70	9·79	0·17	1·8	84
	1936-37	25·2	64·2	12·14	10·17	0·22	2·2	84
	Average	21·7	62·9	11·65	9·61	0·22	2·3	83
Co 244 .	1934-35	18·0	67·3	11·67	9·50	0·23	2·4	81
	1935-36	34·9	65·2	12·05	10·40	0·24	2·3	86
	Average	26·4	66·3	11·86	9·95	8·26	2·4	84
Co 313 .	1936-37	27·4	66·4	13·08	11·08	0·19	1·7	85
Ponda .	1936-37	28·9	74·2	13·41	11·95	0·35	2·9	89
Katha .	1933-34	16·8	54·9	11·03	9·08	0·05	0·4	82
	1934-35	16·3	58·4	11·60	9·15	0·20	2·2	79
	1935-36	15·0	54·3	11·37	9·27	0·08	0·8	82
	1936-37	15·9	58·1	11·77	9·89	0·17	1·7	84
	Average	16·0	56·4	11·45	9·35	0·12	1·3	82

TABLE VI

Amount of juice and sucrose, etc., per acre (in tons) and per ton of cane (Sheikhupura District)

Variety	Year	Weight per acre				Weight per ton of cane		
		Stripped canes	Juice	Total solids	Sucrose	Juice	Total solids	Sucrose
Co 205 .	1934-35	13·3	8·08	1·44	1·10	0·61	0·112	0·085
	1935-36	26·4	15·59	2·70	2·15	0·59	0·102	0·081
	1936-37	24·3	15·31	2·74	2·27	0·63	0·113	0·093
	Average	21·3	13·01	2·29	1·84	0·61	0·108	0·086
Co 213 .	1933-34	14·8	9·62	1·72	1·42	0·65	0·115	0·094
	1934-35	18·1	12·13	2·16	1·79	0·67	0·119	0·099
	1935-36	23·3	15·15	2·81	2·33	0·65	0·121	0·100
	1936-37	28·5	19·38	3·62	3·04	0·68	0·128	0·107
	Average	21·2	14·0	2·58	2·15	0·66	0·121	0·100
Co 223 .	1933-34	14·9	9·54	1·75	1·47	0·64	0·111	0·093
	1934-35	15·4	10·32	1·80	1·44	0·67	0·115	0·093
	1935-36	24·8	15·87	2·90	2·41	0·64	0·117	0·097
	1936-37	22·8	15·28	2·68	2·31	0·67	0·118	0·102
	Average	19·5	12·67	2·28	1·9	0·65	0·111	0·096
Co 244 .	1934-35	18·0	12·06	2·10	1·71	0·67	0·117	0·095
	1935-36	34·87	22·66	4·20	3·62	0·65	0·121	0·104
	Average	26·44	17·46	3·15	2·66	0·66	0·119	0·100
Co 285 .	1933-34	23·9	14·82	2·75	2·26	0·62	0·114	0·093
	1934-35	15·9	10·18	1·84	1·49	0·64	0·114	0·092
	1935-36	21·8	13·52	2·55	2·12	0·62	0·117	0·098
	1936-37	25·2	16·13	2·56	2·12	0·64	0·121	0·102
	Average	21·7	13·67	—2·43	2·00	0·63	0·117	0·096
Co 313 .	1936-37	27·4	18·09	3·58	3·04	0·66	0·131	0·111
Ponda .	1936-37	28·9	21·39	3·88	3·45	0·74	0·134	0·120
Katha .	1933-34	16·8	9·24	1·85	1·52	0·55	0·110	0·091
	1934-35	16·3	9·47	1·90	1·49	0·58	0·116	0·092
	1935-36	15·0	8·10	1·71	1·40	0·54	0·114	0·093
	1936-37	15·9	9·22	1·87	1·33	0·58	0·118	0·099
	Average	16·0	8·96	1·83	1·44	0·56	0·115	0·094

TABLE VII

Composition of juice from different varieties of cane—average of four years (Sheikhupura District)

Variety of cane	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
		Juice	Total solids	Sucrose	Glucose		
Co 205 . . .	21·3	61·1	10·79	8·60	0·53	6·2	80
Co 213 . . .	21·2	66·0	12·08	10·00	0·19	1·9	83
Co 223 . . .	19·5	65·4	11·05	9·63	0·35	3·6	87
Co 244 . . .	26·4	66·3	11·86	9·95	0·24	2·4	84
Co 285 . . .	21·7	62·9	11·65	9·61	0·22	2·3	83
Co 313 . . .	27·4	66·4	13·08	11·08	0·19	1·7	85
Average of Coimbatore canes	22·9	64·7	11·75	9·81	0·29	3·0	84
Katha . . .	16·0	56·4	11·45	9·35	0·12	1·3	82
Ponda . . .	28·9	74·2	13·41	11·95	0·35	2·9	89

TABLE VIII

Period of ripeness for different varieties of cane (Sheikhupura District)

Year	Varieties of cane							
	Katha	Ponda	Co 205	Co 213	Co 223	Co 244	Co 285	Co 313
1934-35 .	26/11 to 6/4	..	27/11 to 19/3	1/1 to 29/3	28/11 to 5/3	28/11 to 4/4	29/11 to 5/4	..
1935-36 .	21/11 to 5/4	..	26/11 to 6/4	3/12 to 2/4	27/11 to 7/4	21/11 to 30/3	19/11 to 7/4	..
1936-37 .	10/11 to 12/4	20/11 to 16/4	6/11 to 18/4	12/11 to 17/4	12/11 to 10/4	.. ..	12/11 to 10/4	5/11 to 7/4
Average .	19/11 to 8/4	20/11 to 16/4	20/11 to 4/4	6/12 to 6/4	22/11 to 23/3	25/11 to 2/4	20/11 to 6/4	5/11 to 7/4

N.B.—The figures for 1933-34 are not included as they were abnormal.

TABLE IX

Average composition of different varieties of sugarcane during maturity period (Lahore District)

Variety	Year	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
			Juice	Total solids	Sucrose	Glucose		
Katha .	1933-34	11·0	53·1	10·30	8·40	0·21	2·5	82
Kahu .	1935-36	6·4	65·1	12·86	10·84	0·35	3·2	84
Ponda .	1933-34	27·9	71·5	12·28	10·98	0·51	4·6	89
	1934-35	18·7	70·8	12·29	11·03	0·39	3·5	90
	1935-36	41·5	72·2	12·81	11·16	0·48	4·3	87
	1936-37	32·3	71·5	12·78	11·32	0·36	3·2	89
	Average	28·8	71·4	12·47	11·08	0·45	4·1	89
Co 205 .	1933-34	27·3	57·9	10·40	8·60	0·48	5·6	83
	1934-35	14·7	59·2	10·05	7·95	0·79	9·9	79
	1935-36	12·1	58·3	10·84	9·11	0·38	4·2	84
	Average	18·0	58·5	10·43	8·55	0·55	6·6	82
Co 223 .	1933-34	17·6	64·4	11·20	9·68	0·45	4·7	86
	1934-35	18·2	65·8	10·76	9·08	0·51	5·6	84
	1935-36	19·8	64·9	11·65	9·92	0·47	4·7	85
	1936-37	16·7	66·7	11·48	9·90	0·38	3·8	86
	Average	17·9	65·6	11·31	9·69	0·44	4·5	86
Co 285 .	1933-34	24·7	59·8	11·40	9·80	0·35	3·6	86
	1934-35	25·3	61·7	11·17	9·47	0·30	3·2	85
	1935-36	19·1	63·3	12·10	10·32	0·24	2·3	85
	1936-37	18·5	64·2	12·09	10·33	0·23	2·2	86
	Average	20·1	63·3	11·84	10·09	0·25	2·5	85
Co 290 .	1933-34	28·8	66·4	12·10	10·40	0·35	3·4	86
	1934-35	15·2	69·0	12·19	10·26	0·45	4·6	84
	1935-36	6·0	64·8	13·04	11·45	0·21	1·8	88
	1936-37	7·0	67·2	12·33	10·89	0·25	2·3	88
	Average	12·8	66·9	12·40	10·78	0·30	2·8	87

TABLE X

Amount of juice and sucrose, etc., per acre (in tons) and per ton of cane (Lahore District)

Variety	Year	Weight per acre				Weight per ton of cane		
		Stripped canes	Juice	Total solids	Sucrose	Juice	Total solids	Sucrose
Katha .	1933-34	11·0	5·84	1·13	0·92	0·53	0·103	0·084
Kahu .	1935-36	6·4	4·17	0·82	0·69	0·65	0·129	0·108
Ponda .	1933-34	27·9	20·0	3·43	3·07	0·72	0·123	0·110
	1934-35	18·7	13·2	2·30	2·06	0·71	0·123	0·110
	1935-36	41·5	30·0	5·32	4·63	0·72	0·128	0·112
	1936-37	32·3	23·1	4·13	3·66	0·72	0·128	0·114
	Average	28·8	20·6	3·59	3·19	0·71	0·125	0·111
Co 205 .	1933-34	27·3	15·8	2·84	2·35	0·58	0·104	0·086
	1934-35	14·7	8·7	1·48	1·17	0·59	0·101	0·080
	1935-36	12·1	7·06	1·31	1·10	0·58	0·108	0·091
	Average	18·0	10·5	1·88	1·54	0·59	0·104	0·086
Co 223 .	1933-34	17·6	11·3	1·97	1·70	0·64	0·112	0·097
	1934-35	18·2	12·0	1·96	1·66	0·66	0·108	0·091
	1935-36	19·8	12·9	2·31	1·96	0·65	0·117	0·099
	1936-37	16·7	11·1	1·92	1·65	0·67	0·115	0·099
	Average	17·9	11·7	2·02	1·73	0·66	0·113	0·097
Co 285 .	1933-34	24·7	14·8	2·82	2·42	0·60	0·114	0·098
	1934-35	25·2	15·6	2·83	2·40	0·62	0·112	0·095
	1935-36	19·1	12·1	2·31	1·97	0·63	0·121	0·103
	1936-37	18·5	11·9	2·24	1·91	0·64	0·121	0·103
	Average	20·1	12·7	2·38	2·03	0·63	0·118	0·101
Co 290 .	1933-34	28·8	19·1	3·49	3·00	0·66	0·121	0·104
	1934-35	15·2	10·5	1·85	1·56	0·69	0·122	0·103
	1935-36	6·0	3·89	0·78	0·69	0·65	0·130	0·115
	1936-37	7·0	4·70	0·86	0·76	0·67	0·123	0·109
	Average.	12·8	8·56	1·59	1·38	0·67	0·124	0·108
Co 312 .	1936-37	7·0	4·61	0·84	0·75	0·66	0·119	0·107

TABLE XI

Composition of juice from different varieties of sugarcane—average of four years (Lahore District)

Variety of cane	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
		Juice	Total solids	Sucrose	Glucose		
Katha . . .	11·0	53·1	10·3	8·4	0·21	2·5	82
Kahu . . .	6·4	65·1	12·86	10·84	0·35	3·2	84
Ponda . . .	28·8	71·4	12·47	11·08	0·45	4·1	89
Co 205 . . .	18·0	58·5	10·43	8·55	0·55	6·6	82
Co 223 . . .	17·9	65·6	11·31	9·69	0·44	4·5	86
Co 285 . . .	20·1	63·3	11·84	10·09	0·25	2·2	85
Co 290 . . .	12·8	66·9	12·40	10·78	0·30	2·8	87
Co 312 . . .	7·0	65·8	11·97	10·68	0·18	1·7	89
Average for Coimbatore canes.	15·2	64·0	11·59	9·96	0·34	3·4	86
Average for Coimbatore canes (excluding Co. 290 & 312).	18·7	62·5	11·19	9·44	0·41	4·3	84

TABLE XII

Period of ripeness for different varieties of sugarcane (Lahore District)

Year	Varieties of cane							
	Katha	Kahu	Ponda	Co 205	Co 223	Co 285	Co 290	Co 312
1933-34 .	5/12 to 19/3	..	6/12 to 13/3	12/12 to 8/4	8/12 to 26/3	12/12 to 8/4	12/12 to 26/3	..
1934-35 .	..	..	9/12 to 21/2	22/12 to 13/4	5/12 to 22/3	18/12 to 1/4	22/12 to 16/2	..
1935-36 .	..	24/11 to 11/3	28/11 to 24/2	7/1 to 14/4	1/12 to 22/3	4/12 to 6/4	15/12 to 17/3	.. ..
1936-37 .	..	..	20/11 to 17/3	..	24/11 to 15/3	13/11 to 9/4	10/11 to 7/3	28/11 to 26/3
Average period of optimum ripeness.	5/12 to 19/3	24/11 to 11/3	1/12 to 5/3	24/12 to 12/4	5/12 to 23/3	4/12 to 6/4	7/12 to 10/3	28/11 to 26/3

TABLE XIII

Average composition of different varieties of sugarcane during maturity period (Montgomery District)

Variety	Year	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity co-efficient
			Juice	Total solids	Sucrose	Glucose		
Katha .	1934-35	16·1	57·3	12·14	9·94	0·10	0·1	82
	1935-36	12·2	57·5	12·45	10·19	0·19	1·8	82
	1936-37	11·4	59·5	12·21	9·79	0·34	3·5	80
	Average	13·0	58·0	12·31	10·03	0·20	1·8	81
Ponda .	1934-35	22·1	71·1	12·81	11·10	0·51	4·7	86
Co. 285 .	1933-34	20·3	60·5	10·98	9·32	0·23	2·5	85
	1934-35	20·9	63·2	11·41	9·52	0·25	2·6	84
	1935-36	23·9	62·4	12·02	10·24	0·17	1·7	85
	1936-37	24·2	64·3	12·15	10·41	0·18	1·7	86
	Average	21·7	60·4	11·27	9·57	0·20	2·1	85
Co. 223 .	1933-34	17·5	63·8	10·96	9·34	0·40	4·3	85
	1934-35	17·3	65·2	10·87	9·13	0·37	4·1	84
	1935-36	22·0	64·9	11·72	10·01	0·29	2·9	85
	1936-37	17·1	66·6	11·66	10·05	0·27	2·7	86
	Average	18·6	65·3	11·36	9·70	0·33	3·4	85
Co. 205 .	1933-34	19·9	59·1	10·30	8·66	0·41	4·7	84
	1934-35	18·8	62·3	10·39	8·37	0·50	6·0	81
	1935-36	20·5	60·6	11·57	9·30	0·43	4·6	81
	Average	19·9	59·8	10·59	8·77	0·43	4·9	83
Co. 270 .	1933-34	15·8	62·6	11·60	10·10	0·30	3·0	87
Co. 290 .	1933-34	18·3	64·9	10·60	8·90	0·83	5·6	84
	1934-35	12·2	67·2	12·09	10·39	0·25	2·4	86
	1935-36	18·3	69·4	13·20	11·77	0·16	1·4	89
	1936-37	21·6	69·7	12·05	10·31	0·22	2·1	86
	Average	16·6	67·9	12·03	10·34	0·27	2·6	86

TABLE XIII—*contd.*

Variety	Year	Weight of stripped cane in tons per acre	Juice	Per cent on cane of			Glucose ratio	Purity co-efficient
				Total solids	Sucrose	Glucose		
Co. 300 .	1934-35	12·7	67·9	12·29	10·60	0·21	2·1	86
	1935-36	27·1	65·9	13·12	11·65	0·09	0·7	89
	1936-37	21·3	66·2	11·76	10·00	0·14	1·4	85
	Average	18·5	67·0	12·36	10·72	0·16	1·6	87
Co. 301 .	1934-35	18·1	67·2	11·82	9·98	0.23	2·3	85
	1935-36	27·1	65·9	13·12	11·65	0·09	0·1	89
	1936-37	21·4	69·1	11·93	9·96	0·20	2·0	84
	Average	22·2	67·4	12·29	10·53	0·17	1·8	86
Co. 312 .	1934-35	16·8	68·2	11·42	9·72	0·24	2·5	85
	1935-36	27·9	66·2	12·50	11·04	0·19	1·4	88
	1936-37	30·4	67·7	11·31	9·42	0·20	2·2	84
	Average	25·8	67·4	11·64	9·97	0·20	2·0	86
Co. 313 .	1934-35 .	10·0	64·9	11·89	10·14	0·18	1·9	85
	1935-36	26·3	67·5	13·23	11·70	0·15	1·3	88
	1936-37	30·8	67·8	13·69	11·87	0·16	1·3	87
	Average	19·3	66·3	12·68	10·96	0·17	1·4	86
Co. 213 .	1933-34	11·0	60·3	11·00	9·20	0·17	1·8	84
	1935-36	20·9	65·9	12·38	10·71	0·16	1·5	87
	1936-37	27·0	67·3	12·87	11·15	0·15	1·3	87
	Average	19·9	64·8	12·16	10·45	0·16	1·5	86
Co .210 ..	1935-36	11·7	66·6	11·96	10·00	0·16	1·6	84

TABLE XIV

Amount of juice and sucrose, etc., per acre (in tons) and per ton of cane (Montgomery District)

Variety	Year	Weight per acre				Weight per ton of cane		
		Stripped canes	Juice	Total solids	Sucrose	Juice	Total solids	Sucrose
Katha	1934-35	16·1	9·2	1·95	1·60	0·51	0·121	0·099
	1935-36	12·2	7·0	1·52	1·24	0·58	0·125	0·102
	1936-37	11·4	6·8	1·39	1·12	0·60	0·122	0·098
	Average	13·0	7·5	1·60	1·30	0·58	0·123	0·100
Ponda	1934-35	22·1	15·7	2·85	2·45	0·71	0·129	0·111
Co 285	1933-34	20·3	12·3	2·23	1·89	0·61	0·110	0·093
	1934-35	20·9	13·2	2·38	1·99	0·63	0·114	0·095
	1935-36	23·9	14·9	2·87	2·45	0·62	0·120	0·102
	1936-37	24·2	15·6	2·94	2·52	0·64	0·122	0·104
	Average	21·7	13·1	2·45	2·08	0·60	0·113	0·096
Co 223	1933-34	17·5	11·2	1·92	1·64	0·64	0·110	0·093
	1934-35	17·3	11·3	1·88	1·58	0·65	0·109	0·091
	1935-36	22·0	14·3	2·58	2·20	0·65	0·117	0·100
	1936-37	17·1	11·4	1·99	1·72	0·67	0·124	0·108
	Average	18·6	12·2	2·11	1·80	0·65	0·114	0·097
Co 205	1933-34	19·9	11·8	2·05	1·72	0·59	0·103	0·087
	1934-35	18·8	11·7	1·95	1·57	0·62	0·104	0·084
	1935-36	20·5	12·4	2·37	1·91	0·61	0·116	0·093
	Average	19·9	11·9	2·11	1·75	0·60	0·106	0·088
Co 270	1933-34	15·8	9·9	1·83	1·60	0·63	0·116	0·101
Co 290	1933-34	18·3	11·90	1·94	1·63	0·65	0·106	0·089
	1934-35	12·2	7·83	1·41	1·21	0·67	0·121	0·104
	1935-36	18·3	12·7	2·42	2·15	0·69	0·132	0·118
	1936-37	21·6	15·1	2·60	2·23	0·70	0·121	0·103
	Average	16·6	11·3	2·00	1·72	0·68	0·120	0·103
Co 300	1934-35	12·7	8·6	1·56	1·35	0·68	0·123	0·106
	1935-36	27·1	17·9	3·56	3·16	0·66	0·131	0·117
	1936-37	21·3	14·1	2·50	2·13	0·66	0·118	0·100
	Average	18·5	12·4	2·29	1·98	0·66	0·124	0·107
Co 301	1934-35	18·1	12·2	2·14	1·81	0·67	0·118	0·100
	1935-36	27·1	17·9	3·56	3·16	0·66	0·131	0·117
	1936-37	21·4	14·8	2·55	2·13	0·69	0·119	0·100
	Average	22·4	15·0	2·73	2·34	0·67	0·123	0·105

TABLE XIV—*contd.*

Variety	Year	Weight per acre				Weight per ton of cane		
		Stripped canes	Juice	Total solids	Sucrose	Juice	Total solids	Sucrose
Co 312	1934-35	16·8	11·5	1·92	1·63	0·68	0·114	0·097
	1935-36	27·9	18·5	3·49	3·08	0·66	0·125	0·110
	1936-37	30·4	20·6	3·44	2·86	0·68	0·113	0·094
	Average	25·8	17·4	3·00	2·57	0·67	0·116	0·100
Co 313	1934-35	10·0	6·5	1·19	1·01	0·65	0·119	0·101
	1935-36	26·3	17·8	3·48	3·08	0·68	0·132	0·117
	1936-37	30·8	20·9	4·22	3·66	0·68	0·137	0·119
	Average.	19·3	12·8	2·45	2·12	0·66	0·127	0·110
Co 213	1933-34	11·0	6·6	1·21	1·01	0·60	0·110	0·092
	1935-36	20·9	13·8	2·59	2·24	0·67	0·124	0·107
	1936-37	27·0	18·2	3·47	3·01	0·67	0·129	0·112
	Average	19·9	12·9	2·42	2·08	0·65	0·122	0·105
Co 210	1935-36	11·7	7·8	1·40	1·17	0·67	0·120	0·100

TABLE XV

Composition of juice from different varieties of sugarcane—average of four years (Montgomery District)

Variety of cane	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
		Juice	Total solids	Sucrose	Glucose		
Katha . . .	13·0	58·0	12·31	10·03	0·20	1·8	82
Ponda . . .	22·1	71·1	12·89	11·10	0·51	4·7	86
Co 205 . . .	19·9	59·8	10·59	8·77	0·43	4·9	83
Co 210 . . .	11·7	66·5	11·96	10·00	0·16	1·6	84
Co 223 . . .	18·6	65·3	11·36	9·70	0·33	3·4	85
Co 213 . . .	19·9	64·8	12·16	10·45	0·16	1·5	86
Co 285 . . .	21·7	60·4	11·27	9·57	0·20	2·1	85
Co 290 . . .	16·6	67·9	12·03	10·34	0·27	2·6	86
Co 300 . . .	18·5	67·0	12·36	10·72	0·16	1·6	87
Co 301 . . .	22·2	67·4	12·29	10·53	0·17	1·8	86
Co 312 . . .	25·8	67·4	11·64	9·97	0·20	2·0	86
Co 313 . . .	19·3	66·3	12·68	10·96	0·17	1·4	86
Co 270 . . .	15·8	62·6	11·60	10·10	0·30	3·0	87
Average of Coimbatore canes.	19·1	64·9	11·81	10·11	0·23	2·3	86

TABLE XVI

Period of optimum ripeness for different varieties of sugarcane (Montgomery District)

Year	Katha	Ponda	Co 205	Co 223	Co 285	Co 290	Co 312	Co 213	Co 210	Co 300	Co 301	C0 313	Co 270
1933-34	...	...	15/12 to 2/4	10/12 to 29/3	12/12 to 5/4	3/12 to 4/3	...	19/12 to 20/3	...	...	...	...	14/12 to 11/4
1934-35	23/11 to 1/3	30/11 to 15/2	29/11 to 30/3	6/12 to 23/3	11/12 to 16/4	11/12 to 26/3	4/12 to 2/4	...	...	27/11 to 16/4	29/12 to 20/4	27/11 to 9/4	...
1935-36	17/11 to 9/4	...	15/12 to 28/3	30/11 to 4/4	17/11 to 11/4	3/12 to 13/4	5/12 to 9/4	25/11 to 15/4	3/12 to 14/4	16/11 to 13/4	1/11 to 13/4	1/11 to 14/4	...
1936-37	24/10 to 17/2	...	...	16/11 to 31/3	10/11 to 2/4	24/11 to 22/3	25/11 to 2/4	24/12 to 7/4	...	5/11 to 1/4	5/11 to 1/4	28/10 to 20/3	...
Average period of optimum ripeness	11/11 to 10/3	30/11 to 15/12	10/12 to 30/3	1/12 to 29/3	28/11 to 9/4	3/12 to 24/3	1/12 to 4/4	13/12 to 4/4	3/12 to 14/4	16/11 to 10/4	22/11 to 11/4	9/11 to 1/4	14/12 to 11/4

TABLE XVII

Average composition of different varieties of sugarcane during maturity period (Multan District)

Variety	Year	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
			Juice	Total solids	Sucrose	Glucose		
Katha .	1934-35	17·6	56·3	11·98	10·20	0·11	1·1	86
	1935-36	14·7	57·4	12·17	10·45	0·07	0·7	86
	1936-37	11·0	56·8	11·83	9·68	0·14	1·5	84
Ponda .	1933-34	21·3	67·3	11·70	10·10	0·27	2·7	86
	1934-35	16·1	69·8	12·10	10·66	0·36	3·5	88
	Average	18·7	68·6	11·90	10·38	0·32	3·1	87
Co 205 .	1933-34	25·2	60·2	10·50	8·60	0·32	3·7	82
	1934-35	17·0	59·0	11·09	9·23	0·46	5·0	83
	1935-36	19·9	60·8	12·07	10·31	0·10	3·1	85
	Average	19·8	59·7	11·19	9·34	0·33	4·2	83
Co 213 .	1933-34	12·9	62·2	9·90	8·40	0·26	3·1	85
	1934-35	8·8	63·6	11·00	9·40	0·06	0·7	86
	Average	10·9	62·9	10·45	8·90	0·16	1·9	86
Co 223 .	1933-34	25·3	64·2	10·25	9·05	0·42	4·7	84
	1934-35	19·7	64·5	10·78	9·14	0·27	3·0	85
	1935-36	20·0	65·1	12·08	10·48	0·18	1·8	87
	1936-37	19·8	66·7	12·09	10·67	0·21	2·0	88
	Average	21·2	64·9	11·26	9·64	0·28	2·9	86
Co 281 .	1933-34	12·4	64·5	11·60	10·00	0·30	3·0	87
	1934-35	9·5	66·5	12·70	10·63	0·10	1·0	87
	Average	11·4	65·5	11·76	10·21	0·23	2·4	87
Co 285 .	1933-34	27·1	59·9	10·95	9·40	0·13	1·0	86
	1934-35	19·7	62·9	11·28	9·17	0·13	1·4	81
	1935-36	25·9	62·1	12·39	10·41	0·10	0·9	84
	1936-37	18·7	63·5	11·63	9·46	0·14	1·4	81
	Average	22·8	62·2	11·62	9·65	0·12	1·3	83
Co 290 .	1933-34	25·2	64·5	11·20	9·65	0·28	2·9	86
	1934-35	20·9	69·1	11·86	9·87	0·26	2·7	83
	1935-36	24·0	66·0	12·96	11·06	0·18	1·6	85
	1936-37	19·0	68·6	12·83	11·27	0·15	1·3	88
	Average	22·9	64·5	12·01	10·30	0·23	2·3	87
Co 312 .	1933-34	17·6	65·1	10·40	8·80	0·32	3·8	85
	1935-36	25·6	67·5	13·09	11·45	0·12	1·1	88
	1936-37	30·2	67·5	12·82	11·18	0·13	1·2	87
	Average	24·5	66·7	12·10	10·48	0·19	2·0	86

TABLE XVIII

Amount of juice and sucrose, etc., per acre (in tons) and per ton of cane (Multan District)

Variety	Year	Weight per acre				Weight per ton of cane		
		Stripped canes	Juice	Total solids	Sucrose	Juice	Total solids	Sucrose
Katha .	1934-35	17·6	9·91	2·11	1·80	0·56	0·120	0·102
	1935-36	14·7	8·44	1·79	1·54	0·57	0·122	0·105
	1936-37	11·0	6·25	1·27	1·07	0·57	0·115	0·097
	Average	14·4	8·18	1·71	1·45	0·57	0·119	0·101
Ponda .	1933-34	21·3	14·3	2·49	2·15	0·67	0·117	0·101
	1934-35	16·1	11·2	1·95	1·72	0·70	0·121	0·107
	Average	18·7	12·8	2·23	1·94	0·69	0·119	0·104
Co 205 .	1933-34	25·2	15·2	2·65	2·17	0·60	0·105	0·086
	1934-35	17·0	10·0	1·89	1·57	0·59	0·111	0·092
	1935-36	19·9	12·1	2·40	2·05	0·61	0·121	0·103
	Average	19·8	11·8	2·22	1·85	0·60	0·112	0·093
Co 223 .	1933-34	25·3	16·2	2·72	2·29	0·64	0·108	0·091
	1934-35	19·7	12·7	2·12	1·80	0·65	0·108	0·091
	1935-36	20·0	13·0	2·42	2·10	0·65	0·121	0·105
	1936-37	19·8	13·2	2·39	2·11	0·67	0·121	0·107
	Average	21·2	13·8	2·39	2·04	0·65	0·113	0·096
Co 285 .	1933-34	27·1	16·2	2·97	2·55	0·60	0·110	0·094
	1934-35	19·7	12·4	2·22	1·81	0·63	0·113	0·092
	1935-36	25·9	16·1	3·21	2·70	0·62	0·124	0·104
	1936-37	18·7	11·9	2·18	1·77	0·64	0·116	0·095
	Average	22·8	14·2	2·65	2·20	0·62	0·116	0·097
Co 281 .	1933-34	12·4	8·0	1·44	1·24	0·65	0·116	0·100
	1934-35	9·5	6·32	1·16	1·01	0·67	0·122	0·106
	Average	11·4	7·42	1·34	1·16	0·65	0·118	0·102
Co 290 .	1933-34	25·2	16·3	2·82	2·43	0·65	0·112	0·097
	1934-35	20·9	14·4	2·48	2·06	0·69	0·119	0·099
	1935-36	24·0	15·8	3·11	2·66	0·66	0·130	0·110
	1936-37	19·0	13·0	2·44	2·14	0·69	0·128	0·113
	Average	22·9	14·8	2·75	2·36	0·65	0·120	0·103
Co 312 .	1933-34	17·6	11·7	1·83	1·55	0·65	0·104	0·088
	1935-36	25·6	17·3	3·35	2·93	0·68	0·131	0·115
	1936-37	30·2	20·4	3·87	3·38	0·68	0·128	0·112
	Average	24·5	16·3	2·97	2·57	0·67	0·121	0·105
Co 213 .	1933-34	12·9	8·02	1·28	1·08	0·062	0·099	0·084
	1934-35	8·8	5·60	0·097	0·083	0·064	0·110	0·094
	Average	10·9	6·86	1·14	0·097	0·063	0·105	0·089

TABLE XIX

Composition of juice from different varieties of cane—average of four years (Multan District)

Variety of cane	Weight of stripped cane in tons per acre	Per cent on cane of				Glucose ratio	Purity coefficient
		Juice	Total solids	Sucrose	Glucose		
Katha . . .	14·4	56·8	11·89	10·11	0·11	1·1	85
Ponda . . .	18·7	68·6	11·90	10·38	0·32	3·1	87
Co 205 . . .	19·8	59·7	11·19	9·34	0·33	4·2	83
Co 223 . . .	21·2	64·9	11·26	9·64	0·28	2·9	86
Co 285 . . .	22·8	62·2	11·62	9·65	0·12	1·3	83
Co 290 . . .	22·9	64·5	12·01	10·30	0·23	2·3	86
Co 281 . . .	11·4	65·1	11·76	10·21	0·23	2·4	87
Co 312 . . .	24·5	66·7	12·10	10·48	0·19	2·0	86
Co 213 . . .	10·9	62·9	10·45	8·90	0·16	1·9	86
Average of Coimbatore canes.	19·1	63·7	11·48	9·79	0·22	2·3	85

TABLE XX

Period of ripeness for different varieties of sugarcane (Multan District)

Year	Varieties of cane								
	Katha	Ponda	Co 205	Co 223	Co 285	Co 290	Co 312	Co 281	Co 213
1933-34	...	11/12 to 6/2	6/12 to 23/3	9/12 to 1/4	16/12 to 25/3	11/12 to 8/4	6/12 to 18/3	6/12 to 8/3	...
1934-35	28/11 to 17/4	11/12 to 19/3	22/12 to 6/4	18/12 to 18/3	9/12 to 2/4	27/11 to 5/3	...	3/12 to 8/4	3/12 to 11/3
1935-36	19/11 to 1/4	...	8/1 to 1/4	1/12 to 25/3	1/12 to 8/4	26/11 to 24/3	26/11 to 7/4	...	...
1936-37	24/10 to 4/4	...	...	23/11 to 3/4	8/11 to 4/4	23/11 to 3/4	23/11 to 3/4	...	...
Average period of optimum ripeness.	13/11 to 7/4	11/12 to 26/2	22/12 to 31/3	5/12 to 27/3	1/12 to 2/4	29/11 to 26/3	28/11 to 30/3	5/12 to 24/3	3/12 to 11/3

TABLE XXI

Locality	Stripped cane in tons per acre		Sucrose in tons per acre	
	Local	Coimbatore	Local	Coimbatore
Rohtak-Karnal . . .	24·6	26·7	1·83	2·35
Jullundur-Hoshiarpur . .	17·3	24·1	1·57	2·62
Gurdaspur-Sialkot . .	11·2	19·6	1·04	1·95
Lahore	8·7	18·7	0·80	1·76
Montgomery . . .	13·0	19·1	1·30	1·93
Multan	14·4	19·1	1·45	1·75
Lyallpur	12·8	18·3	1·35	1·72
Sheikhupura . . .	16·0	22·9	1·44	2·36

Table XXII

Period of ripeness and length of crushing season (in days) for different varieties of cane in different parts of the Punjab

Varieties	Sheikhupura	Lahore	Lyallpur	Montgomery	Multan	Jullundur	Gurdaspur	Rohtak and Karnal
Katha	19/11 to 8/4 (141 days)	5/12 to 19/3 (105 days)	16/11 to 8/4 (145 days)	11/11 to 10/3 (120 days)	13/11 to 7/4 (146 days)	21/11 to 8/3 (108 days)	...	...
Ponda	20/11 to 16/4 (148 days)	1/12 to 5/3 (95 days)	30/11 to 12/3 (103 days)	30/11 to 15/2 (78 days)	11/12 to 26/2 (78 days)	...	...	...
Co 205	20/11 to 4/4 (135 days)	24/12 to 12/4 (110 days)	1/12 to 30/3 (120 days)	10/12 to 30/3 (111 days)	22/12 to 31/3 (100 days)	10/2 to 10/4 (60 days)	31/1 to 2/4 (61 days)	10/1 to 2/4 (83 days)
Co 223	22/11 to 23/3 (122 days)	5/12 to 23/3 (109 days)	26/11 to 5/4 (131 days)	1/12 to 29/3 (119 days)	5/12 to 27/3 (119 days)	15/1 to 21/3 65 (days)	3/1 to 30/3 (87 days)	14/1 to 23/3 (69 days)
Co 285	20/11 to 6/4 (128 days)	4/12 to 6/4 (124 days)	2/12 to 9/4 (129 days)	28/11 to 9/4 (133 days)	1/12 to 2/4 (123 days)	20/1 to 12/4 (83 days)	30/12 to 10/4 (102 days)	...
Co 290	...	7/12 to 10/3 (94 days)	...	3/12 to 24/3 (112 days)	29/11 to 26/3 (118 days)	7/1 to 13/4 (97 days)	22/12 to 28/3 (97 days)	...
Co 312	...	28/11 to 26/3 (119 days)	...	1/12 to 4/4 (125 days)	28/11 to 30/3 (123 days)	...	...	...
Co 281	...	...	...	...	5/12 to 24/3 (110 days)	24/12 to 11/4 (109 days)	...	...
Co 213	6/12 to 6/4 (122 days)	...	8/1 to 7/4 (90 days)	13/12 to 4/4 (113 days)	3/12 to 11/3 (99 days)	22/1 to 13/4 (84 days)	8/1 to 1/4 (83 days)	31/1 to 28/3 (58 days)
Co 210	...	...	...	3/12 to 14/4 (133 days)	...	...	...	...
Co 300	...	...	...	16/11 to 10/4 (146 days)	...	...	15/12 to 20/2 (68 days)	...
Co 301	...	...	...	22/11 to 11/4 (141 days)	...	...	...	...
Co 313	5/11 to 7/4 (154 days)	...	...	9/11 to 1/4 (144 days)	...	...	...	...
Co 270	...	...	...	14/12 to 11/4 119 days)	...	...	...	...
Co 244	25/11 to 2/4 (129 days)	...	...	...	...	...	...	...

TABLE XXIII

Area (in acres) under sugarcane in the Punjab

District	1933-34	1934-35	1935-36	1936-37
Hissar	1,077	758	1,272	2,678
Rohtak	32,053	31,412	29,575	38,167
Gurgaon	7,312	9,805	11,718	13,921
Karnal	25,795	25,095	30,463	37,929
Ambala	22,370	24,490	28,285	29,832
Simla	..	..	..	..
Kangra	4,301	4,317	4,535	5,284
Hoshiarpur	28,461	27,738	28,216	30,523
Jullundur	30,068	34,424	35,252	39,252
Ludhiana	14,182	14,777	17,314	21,020
Ferozepur	7,433	6,097	9,024	15,812
Lahore	18,583	16,617	19,813	28,220
Amritsar	28,724	30,032	28,732	29,989
Gurdaspur	54,220	55,079	53,807	63,934
Sialkot	37,258	37,606	36,386	43,019
Gujranwala	27,519	28,010	27,058	29,888
Sheikhupura	21,790	18,270	16,440	20,493
Gujrat	15,775	15,438	11,459	12,500
Shahpur	9,538	8,266	6,860	7,168
Jhelum	236	311	226	207
Rawalpindi	98	97	114	97
Attock	497	517	721	990
Mianwali	95	47	71	130
Montgomery	13,545	11,378	12,913	14,498
Lyallpur	41,675	42,635	40,918	41,281
Jhang	3,699	4,378	3,788	3,292
Multan	12,178	9,752	12,419	14,892
Muzaffargarh	7,304	4,958	6,631	9,123
D. G. Khan	205	138	190	419
GRAND TOTAL	4,65,991	4,62,442	4,74,200	5,54,348

PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN-CANAL TRACT

I. GERMINATION

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I. Introduction

A vigorous and uniform germination is very important from the standpoint of the practical agriculturist, who, in the absence of the knowledge of the conditions for good germination, always uses a large seed rate as a precaution against low germination, and thus the material, which could be utilised for either *gul* or sugar making, is wasted to a very great extent. In the Deccan-Canal tract, the common practice was to use such a large number as 54,000 eye-buds per acre. Some field experimental work was, therefore, carried out at Manjri on the proper method of planting, and as a result the Bombay Department of Agriculture [Anonymous, 1915] has recommended about 50 per cent reduction in the number of setts required for the purpose. The authors during their first year's physiological investigations, however, observed not only a great deal of variability in the germinative capacity of the

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eye-buds from variety to variety, but even in the same variety if planted at different places and different seasons. This required thorough investigations and the work described in this paper forms a part of these studies.

II. Historical

It is not proposed to go into a detailed historical survey of all the literature on this subject. Only salient features will be touched. Tempany [1924] observes that the young shoot is entirely dependent on the parent stem for nutriment until the fifth week and is capable of drawing from the reserves of food in the portions of the stem, both above and below the node to which the particular eye-bud is attached. Bonazii [1928], on the other hand, states that as the vascular bundles entering a bud are traceable to the internodes immediately below the bud, the young shoot can get its nourishment from that internode only and therefore the lower bud of the piece would find at its disposal only a smaller quantity of reserve material than the others. In the case of two eye-bud setts there is thus a tendency according to him for the upper bud to develop more than the other. Venkatraman [1926] found that removing the reserve tissue from the immediate vicinity of ungerminated cane buds (either by splitting, sectioning, ringing or by removing pith in a seed piece) caused these to germinate much more slowly than untreated buds, showing thereby that germination is to a certain extent dependent upon the presence of reserve material in the seed piece. According to him the ordinary three-budded cane setts contain enough plant food to keep the plant going for at least six weeks.

As regards the chemical processes involved during germination, Tempany [1924] maintains that the storage of sucrose in the stem of the sugarcane is a definite provision for the propagation of the plant by means of shoots from the eye-buds, and in case any inversion takes place as a prelude to metabolism, the reducing sugars formed are used up as fast as they are produced without resulting in any increase in its content. Bonazii [1928] finds that the germinability of cane buds is directly correlated with water and glucose content of the meristematic tissues of the eye-buds, whereas it bears an inverse correlation to the osmotic pressure of the juices circulating in these. According to him the gradients of germination are concomitant with and resulting from accumulation in the juices of the meristematic tissues of high osmotic pressure. From these conclusions he recommends that the selection of canes for vegetative growth is to be done on the basis of individual canes and not on the basis of buds and that seed pieces from the ' upper mature ' portions of a cane which have a more precocious development should therefore obtain preference in field planting. Venkatraman [1929] has found quick and vigorous germination in the unripe portions of the cane and he therefore recommends the planting of unripe canes or unripe portions of canes to get good germination. Evans [1936] has shown a correlation of $-0{\cdot}62 \pm 0{\cdot}097$ between the reducing sugar content and the number of days required for germination ; indicating the desirability of the selection of theplanting material with a high content of reducing sugar,

Methods of soaking setts in water and other chemicals before planting have been tried with success in Porto Rico [May, 1927], Mauritius [Evans, 1936] and India [Khanna, 1934]. Among the various treatments soaking in lime or lime and magnesia has given significantly higher yields. This is explained by the fact that cuttings absorb more water from a lime solution than from pure water.

III. Methods

Botanical

(*1*) *Total height.*—This is measured by the Kamerling's method [1904] which consists of taking the height from the ground level up to the highest visible transverse leaf mark. A flat headed peg is buried to the level of the ground from which all periodical measurements are done in order to avoid the effect of fluctuations in the ground level due to irrigation, interculturing, etc.

(*2*) *Height of millable canes.*—In the flowering varieties like P O J 2878, there is a rapid elongation of the shoot mainly serving as a fore-runner to flowering, which being not important from the economic aspect as contributory to the height of the millable cane, thus tends to create an erroneous conception about the effect of the treatment. This rapid elongation starts much earlier than the emergence of the flag leaf and as it depends on the stage of the growth of the cane even in the same plot, the figures of the measurement of the total height at this period show a great deal of variation between plant to plant requiring a very large number of samples to get an accurate estimate. A modified method to measure the height of the millable cane on the standing crop itself without disturbing its leaves is therefore introduced. It has been observed that when once the internode attains its maximum development, the leaf sheath which till now swathes it tightly shows a distinct tendency to separate from it. This can be readily judged by gently giving a pull to the leaf blade by holding it near the collar mark. The height of the millable cane thus refers to the height up to the transverse mark of the topmost leaf sheath which can be easily separated from the cane by gently pulling the leaf blade. Its comparison with that of the harvested millable cane showed close approximation within five per cent. The method with the complete data will be described in detail in a separate publication.

(*3*) *Circumference.*—This is measured with a cloth tape at the centre of the middle internode of the millable cane. The alternative method of measuring the diameter of the cane by callipers is not followed as, the cane being not perfectly cylindrical, it was found essential to take at least two measurements at right angles to each other at some specific point and when once the cane is lodged this was found to be very difficult and time-consuming. The measurement of the circumference with the cloth tape which can be passed round the internode very easily without the necessity of handling the cane is found to give as accurate results without the disadvantages of the calliper method mentioned above and is therefore adopted throughout.

(*4*) *Leaf area.*—As the determination of the exact leaf area is rather a laborious process, this is represented by the length and width of the leaf.

Only fresh, fully exposed leaf is taken for measurement per each plant as it is considered to give a true estimate of the effect of the treatment. The length is measured from the collar or throat mark to the tip of the leaf blade, while the width is taken at the centre of this total length.

Except as otherwise stated, thirty-six plants per treatment selected at random were taken for all these botanical observations.

Chemical

(*1*) *Glucose.*—This is estimated in the juice by the methylene blue method of Lane and Eynon [1923].

(*2*) *Amide nitrogen.*—The method of Vickery and Pucher [1931] of preliminary boiling the juice with sulphuric acid is followed. It is then neutralised with sodium carbonate and distilled with magnesia as usual.

IV. Experimental

A. Relation of germination to the climatic factors

In the Deccan-canal tract, the plant cane is normally planted from mid-January to mid-March while 'Adsali' (18 months' crop) is planted from mid-June to mid-August. With the introduction of the new promising Coimbatore varieties, the method of early planting—mid-October onwards—is also coming into vogue. A great deal of variation has been observed both in the rapidity of germination as well as in the final percentage germination in these different plantings. Apparently this seems to be due to the differences in the temperatures during this period and it is felt therefore essential to find out the optimum temperatures so as to adjust the planting time accordingly.

This problem of the influence of climate is, however, complicated by the fact that sugarcane is propagated by setts which are found to differ greatly in the chemical composition according to their period of growth, previous treatment as well as the season prevalent at the time of planting. Under such circumstances the most conclusive experimental technique would have been to run these experiments all at one time with the same planting material but with varying treatments of controlled temperatures. This, however, involved large outlay and was not found to be practicable. Attempts have been therefore made to elucidate this problem by field experiments supplemented by laboratory investigations. For this purpose special plantings were done in six replicated rows at different periods from mid-November to end of February during the last two years and quantitative data on periodical germination and atmospheric as well as soil temperatures (four days counts) were collected. In one series the planting material was obtained from the same treatment throughout, while in another the effect of different manurial treatments was also tested. In all cases, however, the planting material was analysed for amide nitrogen and glucose—the important food constituents in the metabolism of the germinating bud. The results of only one of the series are given in Table I, with only three weeks germination and average atmospheric temperatures during this period.

TABLE I

Relation of temperatures to germination

(Average of six replicates with 90 eye-buds in each)

Serial No.	Date of planting	Germination at 3 weeks		Average temperatures of 3 weeks			No. of days with minimum temperature below 50°F. within the period	Amide N (mg. per 100 grms. of juice)		Glucose (grms. per 100 grms. of juice)	
		Pundia (per cent)	P O J 2878 (per cent)	Max. (°F.)	Min. (°F.)	Mean (°F.)		*Pundia*	P O J 2878	*Pundia*	P O J 2878
1	2	3	4	5	6	7	8	9	10	11	12
1	26th November 1936 . .	18·7±1·03	3·7±0·67	83·6	51·5	65·5	5	0·78	1·47	3·65	1·22
2	10th December 1936 . .	3·1±0·58	2·4±0·77	84·6	49·3	66·9	13	1·05	2·13	2·40	0·78
3	26th December 1936 . .	3·5±1·62	1·7±1·23	83·5	42·8	63·1	22	1·47*	2·01	2·08	0·56
4	9th January 1937 . .	6·3±0·54	14·8±1·65	86·8	47·9	67·3	14	1·89	2·25	1·82	0·30
5	26th January 1937 . .	39·5±3·17	51·3±1·40	89·1	54·7	71·9	4	1·61	2·52*	1·71	0·24
6	10th February 1937 . .	23·7±2·08	28·7±1·97	89·6	53·8	71·7	4	1·56	2·80	1·62	0·21
7	26th February 1937 . .	39·3±3·55	48·7±3·42	95·4	57·8	76·6	1	1·27	2·38	1·53	0·55

* These figures have been obtained by interpolation.

TABLE II

Relation of temperatures to germination

(Average of 12 replicated rows with 105 eye-buds in each)

Period of observations	1934 (Date of planting 16-1-1934)				1935 (Date of planting 18-1-1935)			
	Germination per cent within the period		Average atmospheric temperature within the period		Germination per cent within the period		Average atmospheric temperature within the period	
	Pundia	P O J 2878	Maximum (°F.)	Minimum (°F.)	*Pundia*	P O J 2878	Maximum (°F.)	Minimum (°F.)
1	2	3	4	5	6	7	8	9
23 days from planting	9·4	1·5	85·5	48·1	30·9	24·4	89·5	52·0
24 to 31 days from planting	19·7	14·1	92·8	52·2	16·3	32·5	90·3	53·0
32 to 39 days from planting	16·4	22·0	93·8	54·9	11·8	13·5	92·4	50·6
40 to 47 days from planting	7·6	13·2	94·5	53·7	6·2	9·2	90·8	51·7
48 to 55 days from planting	3·6	6·5	92·5	54·9	5·0	1·8	92·7	51·6
Total germination per cent (8 weeks) . .	56·7	57·3	...	...	70·2	81·4	...	...
Total germination per cent (10 weeks) . .	61·2	64·5	...	...	...	...	...	...

As the germination generally takes from 6 to 8 weeks for its completion, the figures for three weeks germination are expected to give a very good idea about rapidity which, as would be shown later, also influences the total germination. The comparison of these figures with the chemical constituents brings out clearly the influence of the climate. While with the advanced age of the planting material, there is a tendency towards the fall in the assimilable food reserves especially glucose (cols. 8 to 11), there is a significant increase in the germination percentage which can be attributed only to the rise in the minimum temperatures. The inhibitory effect of the minimum temperatures below 50°F. is also evident.

In order to further differentiate between the relative importance of the temperatures and chemical constituents, these data have been put to the statistical test of correlation. It would be seen that there is a high correlation with the minimum temperatures ($+0{\cdot}72 \pm 0{\cdot}037$) while none has been obtained with amide N ($+0{\cdot}31 \pm 0{\cdot}067$) or with glucose ($+0{\cdot}03 \pm 0{\cdot}074$).

It must, however, be emphasised here that this lack of correlation should not be interpreted as non-influence of the chemical constituents on germination. It only clearly brings out the predominating influence of the temperatures. As would be shown later, there is a distinct variability in the germination according to the previous treatment of the planting material even when planted under the same conditions of temperature, and under these circumstances the influence of the chemical nature of the material would be quite apparent.

The advantages of the speed of germination are two-fold. It leads to the increase in the total germination. This is very well illustrated in Table II, which gives the comparative results of germination in a large-scale experiment for two years, one of which has experienced low temperatures.

The material for planting used in both the years had received exactly the same previous treatment and was of the same age, the planting time being mid-January in both the cases. No analysis of the material was carried out, but under these circumstances there would be no great variation in its chemical composition. The slow rate of germination in the first three weeks during the season of 1934 is therefore due to the low temperatures prevalent during the period. During this season, some of the buds sprouted even after eight weeks—the normal period required for complete germination. The total germination even after ten weeks has, however, been much less. The influence of the rapidity on the final success in germination is also evident from Figs. 1 and 2.

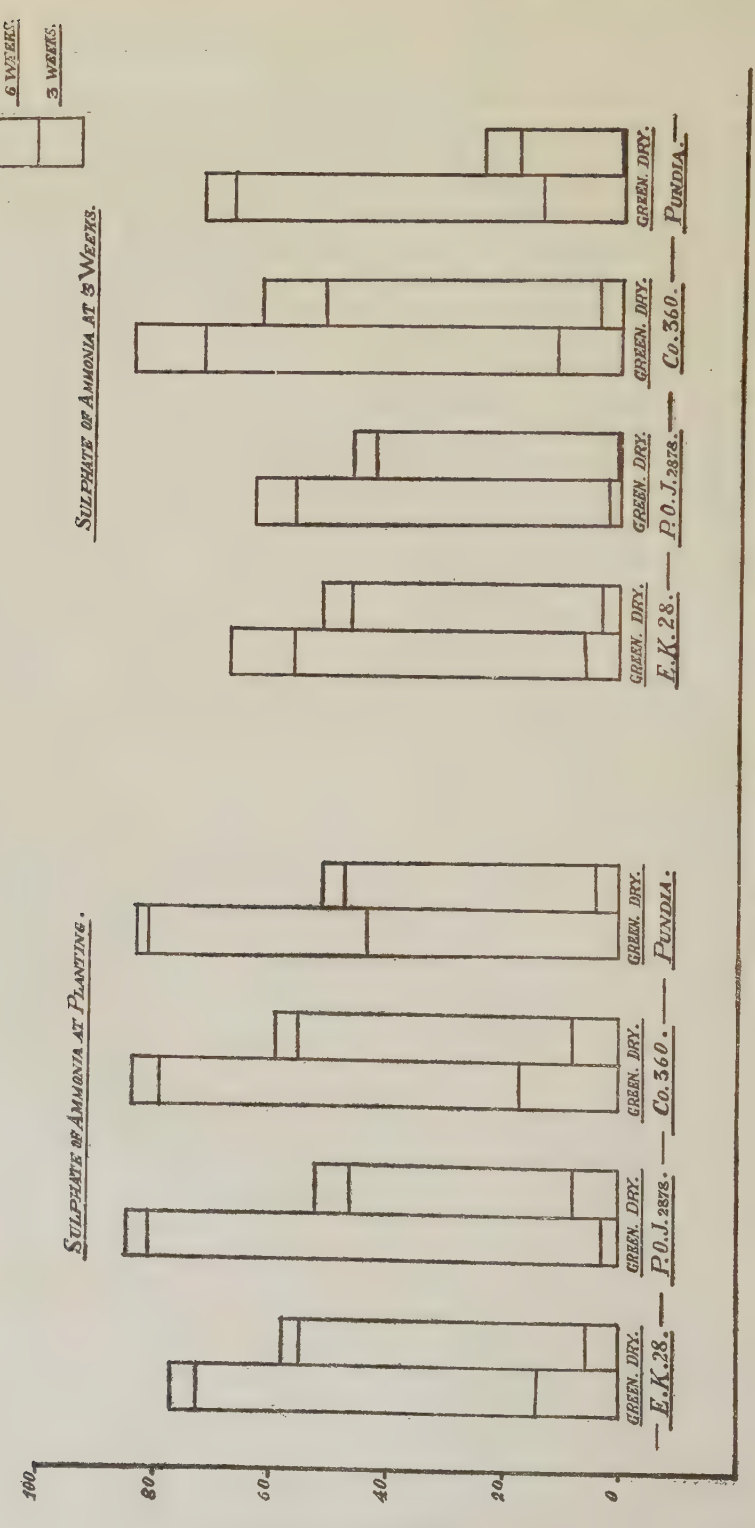

FIG. 1. Green *vs.* dry-scaled buds (periodical germination)

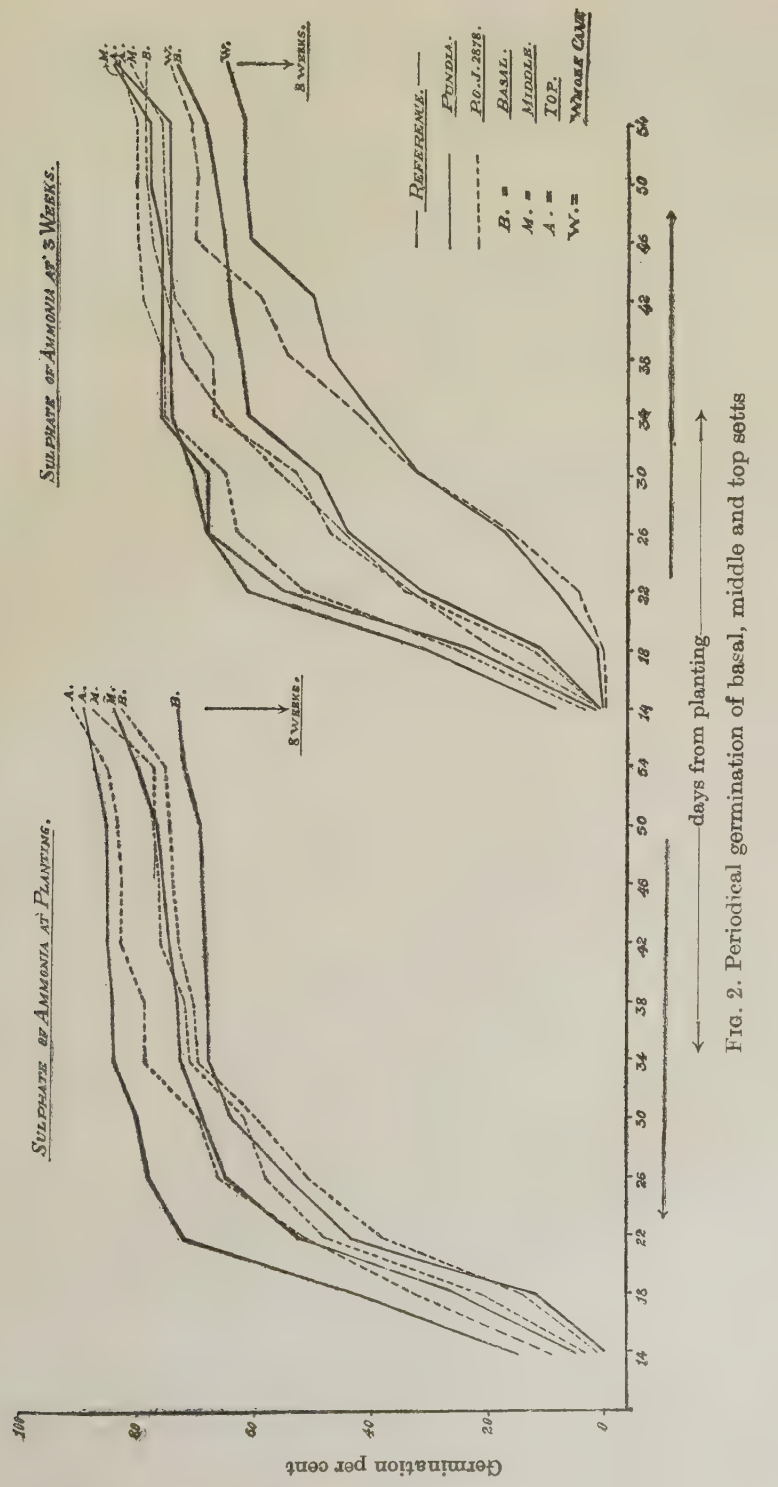

FIG. 2. Periodical germination of basal, middle and top setts

The inspection of the crop has shown that shoots of early germinated buds are generally vigorous and are thus capable of withstanding the borer attack to a great extent. Attempts were further made during the season of 1935 to find out whether this vigour is continued throughout the growing period. For this purpose it was proposed to label ninety shoots from each of those germinated within three, six and eight weeks from two varieties and record their periodical growth by botanical observations. In the case of eight weeks, only about half the number of plants was available at start due to quick germination during this season and this was further greatly reduced by the borer attack, so that by August the observations in this case had to be dropped due to the availability of very few number of plants. The results are given in Table III.

TABLE III

Developmental studies

(*Average of 90 labelled plants; date of planting 19-1-35*)

	2 months total height	6 months total height	10 months		Harvest time	
			Height of millable canes	Circum-ference	Height of millable canes	Circum-ference
1	2	3	4	5	6	7
	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)
Pundia—						
3 weeks plants . .	12·7	20·0	62·9	4·3	88·7	4·6
6 weeks plants . .	11·0	19·1	59·6	4·3	83·4	4·4
POJ 2878—						
3 weeks plants . .	12·9	26·7	72·6	3·9	94·4	3·9
6 weeks plants . .	12·0	25·8	72·2	3·7	95·1	3·9

It would be seen that while there are indications of a better performance during early stages in the case of plants germinating within three weeks, this advantage is not maintained throughout the growth period and as a result no significant differences are seen at harvest time between these and the plants germinating within six weeks. In the January planting, further delay in germination is, however, definitely deleterious specially due to intense borer attack.

B. Soil—its influence on germination

The soils of the Deccan-canal tract can be included in the broad group of regur or black cotton soil. This is at present being surveyed according to the modern method of genetic soil classification by the Soil Physicist of the scheme, who has so far identified some eight distinct soil types varying in physical and chemical characteristics. It is felt that the system of planting in vogue may not be suitable to all the types and would have to be varied according to their physical nature.

The general system of planting prevalent in this tract is to open out furrows, irrigate them and after allowing the water to soak for some time, press the setts with foot keeping the eye-buds at the sides. Further, short

period irrigations called '*ambavni*' and '*chimbavni*' are given at intervals of four to five days after which regular irrigation at ten days interval starts. There is thus no dearth of moisture to the sett throughout its germinative period. One of the essentials for successful germination is found to be, however, not to plant them too deep in the soil. Planting to a depth of one to two inches is found to be most suitable in all the seasons while during favourable temperatures, surface planting, *i.e.*, planting in flush with the surface of the soil leads to a greater rapidity in germination. In the case of the occurrence of low temperatures, however, there is the risk of the damage to the tender eye-buds due to shrivelling in the latter method.

During the first year (1933) of our experiment in the heavy soil, it was found that in this soil this method of planting leads to the placing of the setts at a much lower depth than is essential for good germination. The very low germination (50 per cent) obtained during this year in spite of favourable temperatures was actually traced to this fact by digging out the ungerminated setts and measuring the depth at which they were lying. It has been observed that after heavy irrigation or rain, such soils get puddled and soft and in walking over them the foot sinks easily into the soil. There is thus always the risk of deep planting by this method which would require a very careful manipulation in pressing the setts. Pressing the setts down into the soil by the hand instead of the usual method of pressing down by foot leads to some improvement; but the most suitable system is found to be the dry planting method, in which case the setts are placed in position in the furrows with just sufficient dry soil to cover them. The furrows are then irrigated with a very slow flow of water in order to minimise the accumulation of soil on the surface. Such slow irrigations will have to be continued for the first three or four irrigations till the soil at the sides of the furrows settles down, after which the system of normal irrigation may be followed. It has given 60 per cent success during unfavourable temperatures of 1934, while under normal conditions about 70 to 80 per cent germination has been obtained. The method also enables efficient supervision on the workmen, as the whole process is capable of inspection without any damage to the sett, and in case of its deeper placing, the mistake can be immediately rectified before irrigation. The Imperial Sugarcane Breeding Station at Coimbatore has now evolved some varieties capable of thriving in soils having bad tilth (chopanised soil). The main difficulty is, however, to get the eye-buds to germinate in these soils. With the adoption of this method of planting, however, the Agricultural Section has been able to secure a very good germination with these varieties.

It has been also observed that in the usual method of planting there is a possibility of deeper embedding of the setts in other soils as well, mainly due to carelessness or ignorance on the part of the workmen. In such cases, however, skipping off one or two irrigations has resulted in great improvement. In fact, it has been our experience that the reduction in the number of irrigational turns helps in accelerating the rate of germination and the second short period irrigation (*chimbavni*) is entirely superfluous, while even the first (*ambavni*) should be dropped in case there is not much cracking of the soil after initial soaking.

C. Eye-buds—influence of their morphological characteristics on germination

According to Earle [1928], morphological bud characters are less variable and less dependent on growth conditions than any other part of the cane plant and can be mainly depended upon for recognising the varieties. It was therefore felt that the variability in the rate of germination among the varieties even under the optimum environmental condition of soil and climate described above might be due to the inherent differences in these bud characters of the varieties themselves. A careful examination of the buds was, therefore, undertaken as regards their size, shape and the position of the point of germination in relation to their germinative capacity. The results, however, did not show any correlation with the differences in these characters. Even in the same cane, the variability observed in the size and shape of the eye-buds at different positions has not been found to influence their power of germination in any way. It was, however, found that the rapidity of germination in the different varieties is greatly affected by one important factor, *viz.*, the presence of dry scale leaves on the buds. The proportion of such buds vary considerably from variety to variety. Further they are found all along the cane although their number is greater in the bottom portion which is known to be very slow in germination. The cause of the drying of the scale leaves of the eye-buds is not exactly known. This process of drying progresses from outwards and buds with a varying number of dry scales are met with on the same cane. In extreme cases only, when the drying extends to the growing point, the bud sometimes presents a shrivelled appearance or becomes soft to the touch with the complete cessation of its activity. During the selection of planting material, such eye-buds are invariably eliminated. In other cases, in which the drying is only in the superficial leaves, the buds otherwise retain their healthy appearance and are quite capable of germination, and the general practice in this tract is to include them in the planting material. In future discussions such buds are termed, for the sake of convenience, dry-scaled buds, while buds with all the scales green are called green-scaled ones.

The observation about the retardation in the rate of germination due to the drying of the scale leaves is quantitatively tested by two types of field experiments. In the first one the germinative capacity of dry-scaled buds and its influence on the development of the crop and yield have been compared with those of the green ones. For this purpose, these two types of buds were separated from the whole cane—about twelve months old—and were planted in different rows. Their periodical germination is illustrated in Fig. 1. A definite decline in the rate of germination is evident in the case of dry-scaled eye-buds which is also reflected in their total germination. In the case of the green-scaled buds the columns bring out an interesting fact that with the application of sulphate of ammonia at the time of planting, the figures for the total germination are almost similar and thus by this method of selection and treatment, the variation in the germinative capacity between the varieties will be greatly minimised. The data about the development of the crop and cane yields are given in Table IV.

TABLE IV

Green-scaled vs. *dry-scaled buds*

(*Average of two replicated rows, each row containing 90 single-budded setts*)

Variety and buds planted	Sulphate of ammonia at start							Sulphate of ammonia at 3 weeks						
	Per cent decrease in germination at 8 weeks of dry-scaled buds over green	Ratio of tillers to mother cane at harvest time (per cent)	October		Per 3 ft. strip at harvest time			Per cent decrease in germination at 8 weeks of dry-scaled buds over green	Ratio of tillers to mother cane at harvest time (per cent)	October		Per 3 ft. strip at harvest time		
			Height of millable canes (in.)	Circumference (in.)	No. of canes	Weight of canes (lbs.)	Decrease in cane weight of dry-scaled buds over green (per cent)			Height of millable canes (in.)	Circumference (in.)	No. of canes	Weight of canes (lbs.)	Decrease in cane weight of dry-scaled buds over green (per cent)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
E K 28—														
Green .	—24·3	—1·4	69·3	4·3	6·9	31·0	—28·1	—24·6	—26·2	74·2	4·9	4·5	22·2	—34·2
Dry . .		—7·5	68·9	4·1	4·9	22·3			—28·4	60·8	4·4	3·3	14·6	
POJ 2878—														
Green .	—39·0	48·1	80·2	3·5	11·4	32·0	—18·8	—26·4	54·4	55·3	3·7	8·8	25·9	—21·2
Dry . .		87·2	61·2	3·4	8·8	26·0			81·0	41·8	3·7	7·6	20·4	
Co 360—														
Green .	—28·9	36·8	72·3	3·3	10·4	29·9	—1·0	—26·3	—2·6	59·9	3·6	7·4	21·5	+5·1
Dry . .		111·1	62·3	3·0	11·4	29·6			71·4	68·5	4·0	9·6	22·6	
Pundia—														
Green .	—38·7	—2·7	69·0	4·5	7·3	24·0	—26·1	—66·2	—61·5	...	...	2·5	...	...
Dry . .		0·0	63·7	4·4	4·6	17·6			36·4	...	...	3·0	...	

Except in Co 360, the falling off in germination in the case of dry-scaled buds has influenced the yields, although due to greater tillering (columns 3 and 10) as a result of more available space, the deleterious effect of the low germination is reduced to some extent.

In the other experiment, the dry-scaled buds were entirely left out of the planting material. The experiment was conducted with two varieties—*Pundia* and P O J 2878—and the method consisted of dividing the individual canes (of the same age as used in the previous experiment) in three equal portions from each of which three-budded setts possessing green scales only were selected as planting material. The germination counts are taken every four days after the first fortnight from planting and these are plotted in Fig. 2. There is a distinct fall in the rapidity of germination of the buds from both bottom and middle portions when compared to that of the buds in the top portion. By the time of the completion of the germination however, a close agreement is seen between the curves for middle and top portions while that for the bottom one shows slightly lower trend. This difference between the germinative capacity of the three portions of the cane does no doubt indicate that there are other influencing factors besides the morphological characteristics of the buds ; but when the curves for these different portions are compared with those for the general method of planting (plotted in addition under " sulphate of ammonia at three weeks " from the figures of the adjoining plot) in which three-budded setts from the whole cane are utilised for planting without the elimination of dry-scaled buds, significant improvement in the rapidity of germination is evidenced by this method of selection even in the basal portion. Further development of the crop and yield data have also shown that this slight decrease in germination in the basal portion is apparently obliterated during the period of growth (Table V) and it is thus quite evident that by this method of selection of eye-buds, good germination and yield can be secured, whatever may be their position on the cane itself.

Table V

Periodical germination and harvest time data of bottom, middle and top setts (Averages of 3 replicated rows with 35 three-budded setts per each row)

Treatment	Germination per cent			Harvest time data				
	Three weeks	Six weeks	Eight weeks	Height of millable cane	Circum-ference	No. of canes per 3 ft.	Weight per cane	Brix
1	2	3	4	5	6	7	8	9
P O J 2878—				(in.)	(in.)		(lbs.)	
Sulphate of ammonia at start—								
Bottom	27·3	73·0	82·8	96·4	3·8	8·2	3·2	21·47
Middle	44·4	76·0	86·9	98·8	3·9	8·0	3·0	21·72
Top	48·2	83·0	91·4	99·7	3·9	8·7	2·8	21·69
Sulphate of ammonia at 3 weeks—								
Bottom	29·8	75·0	78·1	94·1	3·7	7·8	3·3	21·72
Middle	29·6	74·0	81·2	94·4	3·95	8·0	3·2	21·22
Top	41·6	79·0	82·5	88·2	3·9	8·9	3·3	20·72
Pundia—								
Sulphate of ammonia at start—								
Bottom	36·2	68·5	73·0	88·7	4·7	5·3	4·0	17·70
Middle	42·5	47·5	84·4	84·4	4·2	7·6	3·8	17·97
Top	64·1	85·0	88·9	90·5	4·3	5·1	4·0	17·70
Sulphate of ammonia at 3 weeks—								
Bottom	26·6	64·0	73·0	86·0	4·3	4·4	4·3	18·22
Middle	46·3	75·5	83·8	78·3	4·6	6·5	3·7	18·15
Top	47·6	74·0	83·2	86·8	4·7	6·4	4·2	18·40

In order to find out the ratios of dry-scaled buds to green-scaled ones in the different varieties, a number of canes twelve months old, under the same treatment were examined for a few varieties. For this purpose individual canes were divided into three equal portions, on each of which separate counts were taken. The results are given in Table VI and are the mean values of 50 randomly selected canes.

TABLE VI

Per cent ratio of green and dry-scaled buds

Percentages are calculated from the mean values of 50 randomly selected canes

Variety	Bottom one-third		Middle one-third		Top one-third		Total	
	Green	Dry	Green	Dry	Green	Dry	Green	Dry
1	2	3	4	5	6	7	8	9
Co 419	57·9	42·3	85·5	14·5	95·9	4·1	79·8	20·3
Pundia	48·5	51·5	84·2	15·8	99·2	0·8	77·3	22·7
Co 360	72·6	27·4	88·3	11·7	96·0	4·0	85·6	14·4
H M 320	16·0	84·0	45·5	54·5	77·3	22·7	46·3	53·7
P O J 2878 . . .	39·0	61·0	84·4	15·6	97·9	2·1	78·8	26·2
E K 28	8·7	91·3	36·3	63·7	63·3	36·7	36·1	63·9

It would be seen that the basal portion contains the largest number of dry-scaled buds and the top portion the least in all the varieties. Among the varieties, E K 28 possesses the largest number of dry-scaled buds and this variety is known to give very low germination. The experimental evidence about the deleterious effect of dry-scaled buds adduced above thus conclusively demonstrates that a great deal of variability in the germinative capacity among the varieties can be reduced by the elimination of dry-scaled buds as the different proportions of these buds seem to be the main cause for this variation. Further with the application of sulphate of ammonia at the time of planting to green-scaled buds uniform germination is secured (Fig. 1) in all the varieties tested. This information about the selection of the eye-buds would therefore be very important from the standpoint of the practical agriculturist, who, because of the variable germination that he is at present getting from the different varieties is perplexed as to the number of setts he should plant.

It has already been stated that except for a few dry scale leaves, the buds otherwise exhibit outwardly quite a healthy appearance and are capable of germination. What are then the physiological changes which bring about this retardation in the rate of germination ? One of the effects of the presence of the dry scale leaves is found to be the reduction in the water content of the buds. Dry-scaled eye-buds from twelve months old crop under the same treatment were analysed for their moisture content in comparison with the green-scaled ones. Table VII gives the average figure of four independent determinations in each variety.

TABLE VII

Moisture content of green and dry scaled eye-buds

(*Average of four independent determinations on ten buds per each determination*)

Variety	Eye-buds	Percentage moisture*		
		Original	After soaking for 24 hours	Absorption
1	2	3	4	5
1 P O J 2878 . .	Green . .	69·5±0·68	80·7	11·2
	Dry . .	60·3±2·11	76·2	15·9
2 *Pundia* . . .	Green . .	71·3±1·34	79·1	7·8
	Dry . .	66·0±0·99	76·0	10·0
3 Co 419 . . .	Green . .	81·9±0·95	82·7	0·8
	Dry . .	75·8±1·30	78·1	2·4
4 Co 413 . . .	Green . .	81·1±1·31	83·1	2·0
	Dry . .	76·1±2·12	78·8	2·7
5 Co 360 . . .	Green . .	84·8±1·47	85·0	0·2
	Dry . .	76·1±0·95	77·9	1·8

* While the determinations of the moisture content of both types of buds per variety were made at the same time the varieties were taken at two periods due to the non-availability of all the varieties at the same period. Thus the determinations for the varieties 1 and 2 were done in March, while those for the rest were done in September 1937. The higher moisture content in the latter is due to this.

It will be seen that in all the varieties there is a definite lowering of the moisture content in the dry-scaled buds in comparison with that of the green-scaled ones. Further studies on the absorption of moisture after soaking for twenty-four hours have shown that the dry-scaled buds are capable of absorbing water rapidly (Table VII, columns 4 and 5). Interesting differences between the two types of buds are, however, found from their microscopic examination. In the green-scaled ones, there is a slight swelling of the scales after soaking thus facilitating their easy separation. In the other case no change has been observed due to soaking, the dry scales remaining sticking to the inner scale leaves as tightly as in their original condition. Bonazii [1928] has maintained that the germinability of cane buds is directly correlated with water and glucose content of the meristematic tissues of the eye-buds. As will be shown later, no correlation of glucose with the germinative capacity of the buds has been observed by us under the conditions of our experiment. As the dry-scaled buds are found to be capable of absorbing

water very rapidly, this should not be also a limiting factor under the conditions of irrigation. We are therefore inclined to the view that the delay in germination in the case of dry-scaled buds is either mainly due to the mechanical obstruction to the emergence of the growing point or to the retardation of gases to or from it. The removal of dry-scale leaves from such buds by careful teasing with needles has in fact resulted in the acceleration in the rate of germination (Table VIII).

TABLE VIII

Effect of the removal of dry-scale leaves of buds on germination

(*Average of 2 replicates with 27 eye-buds in each ; Variety—P O J 2878 ; germination per cent*)

Kinds of buds planted	Days after planting								
	16	20	24	28	32	36	40	44	48
With dry scales .	0	0	0	11·1	13·0	18·5	27·7	27·7	48·1
With dry scales removed	0	1·9	8·1	18·5	31·5	35·2	38·9	38·9	51·9

In the Deccan-canal tract the whole cane is used as planting material and usually these canes are taken from the ordinary plantation without maintaining special nurseries for the same. The ratio of dry-scaled to green-scaled buds given in Table VI shows that in some of the varieties, the proportion of dry-scaled buds is very great and their elimination may not be thus practicable. The improvement in their germinative capacity by the removal of dry-scale leaves suggested a possible solution ; but the method is too laborious requiring careful manipulation and will be thus impracticable. Investigations are in progress to find out a suitable method for the utilisation of such buds and these will be dealt with in a later publication.

D. Type of the sett—its influence on germination

The general practice in this tract is to utilise three-budded setts for planting. It was felt, however, that with the above knowledge about the selection of eye-buds there would be a greater possibility of rigid selection if these were substituted with the single-budded setts as the planting material. Kulkarni [1918] has in fact shown a very high germination in the case of single-budded setts in comparison with the three-budded ones. His method of planting, however, differed in both the cases, the former being planted with the bud upwards, while in the case of the latter, the buds were kept sidewards. Even with the sideward method of planting in both the cases, we have observed a higher rate of germination in the single-budded setts. These figures are represented in Fig. 3. The better performance in the single-budded sett is considered to be mainly due to the possibility of its better selection. The low temperatures experienced during the season of 1934 have affected the germination of this year in the case of *Pundia*. It is observed that under such circumstances single-budded setts are likely to be damaged by these temperatures much more quickly than the three-budded setts.

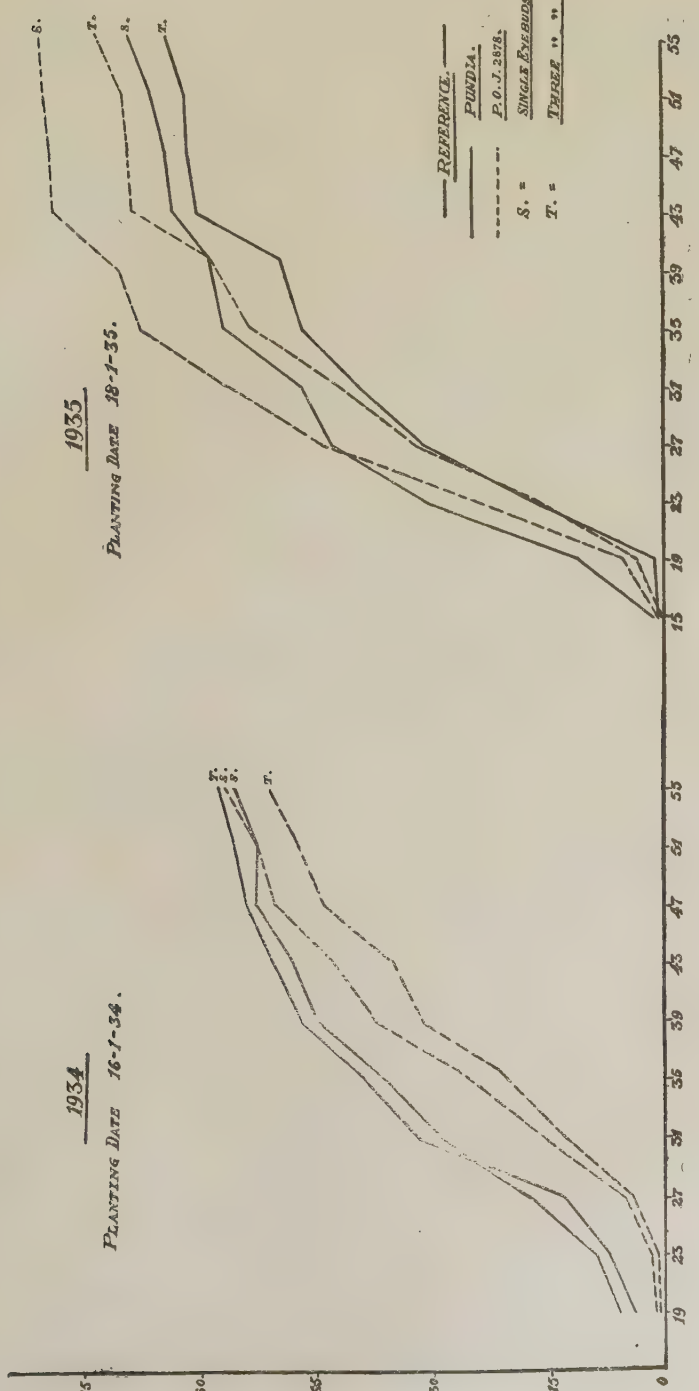

FIG. 3. Single *vs.* three eye-bud setts (periodical germination)

Inspection of the crop in both the series, however, showed the plants from the single eye-bud setts to be not so vigorous as in the case of the three eye-bud setts. These were invariably thinner with less height and the leaves appeared to be narrower than in the other case. This effect was very pronounced during the early stages of growth—for four to five months from planting but was hardly visible at a later stage—about a month after earthing up. A special experiment was therefore laid out to test this quantitatively with one variety—P O J 2878 only—under four manurial doses varying from 225 to 600 lbs. nitrogen. The crop was harvested periodically, seven 3-feet strips being cut at each period and weighed separately. For this purpose, the two end rows and 4-feet on either side of the intermediate rows were excluded from sampling in order to avoid the border effect. The remaining lengths of the rows were then divided into 3-feet strips from which only alternate strips were utilised for sampling by random selection. By this method there was no possibility of any of the selected strips abutting on the previously sampled one. The results of variation in yield are as follows.

TABLE IX

Single eye-buds vs. *three eye-buds*
(*Variety, P O J 2878*)

Treatments	Per cent variation in yield of single eye-buds from three eye-buds (Average of seven 3-feet strips)		
	July	October	Harvest time
225 N	—65·8	—30·0	—16·2
300 N	—68·4	—45·1	—16·0
450 N	—41·7	—18·8	+18·4
600 N	—24·7	—28·2	—14·1

It would be seen that there is a definite lowering of the physiological performance throughout the earlier stages of the life-cycle of the plant in the case of single eye-bud sett. Due to controlled conditions of irrigation and manuring these differences are, however, greatly minimised with the progress of growth specially in the higher nitrogenous treatments. The higher yields reported by Kulkarni [1919] in the case of single-budded setts are due to his adopting the artificial method of removing all the tillers as they appeared and allowing only the mother canes to develop in both the treatments. This prevented the other treatment from adjusting by tillering the fall in the number of plants as a result of less germination.

While in the normally cut single-budded setts, the germinative capacity is not in any way lowered, further reduction in the size of these setts by cutting them close to the eye-buds is found to affect both the speed of germination as well as the total success.

TABLE X

Performance of close-cut and ordinary single-budded setts

(*Average of 112 eye-buds*)

Type of setts planted	Germination (per cent)			At 4 months		
	Three weeks	Six weeks	Eight weeks	Total height (in.)	Length of leaves (in.)	Breadth of leaves (in.)
Close cut—						
Single eye-buds . .	16·2	38·4	42·3	14·5	44·1	2·03
Ordinary—						
Single eye-buds . .	20·4	53·2	53·9	17·4	46·5	2·12

It is thus quite evident from all this experimental evidence that the reserve material in the seed piece not only makes a definite contribution to the nutrition of the developing plant in the early stages of its growth but even exercises an important control on the process of germination.

E. Chemical basis of germination

It is a matter of general belief that buds from either immature canes or immature portions of canes germinate quicker than those from the mature ones, and on this basis canes eight to ten months old are considered as the suitable planting material. It has, however, been found that due to the susceptibility to the borer attack, the March or April plantings for securing this type of planting material for the January season are not advisable. It would thus be necessary to find out a suitable alternative method to overcome this difficulty. The differences in the germinative capacity of the different portions of the cane, which are very well illustrated in Fig. 1 (already discussed in section C) where in spite of careful selection of buds, the rate of germination in the bottom portion is lower than in the other two portions, suggested the possibility of the chemical composition of the reserve material of the sett as a predominating factor. In order to throw further light on this, three-budded setts from the canes of the same age but under varying nitrogenous treatments were planted in sand, washed free from all soluble constituents, so as to entirely eliminate the effect of soil nutrients. These experiments were repeated at three different periods with the planting material of eight, ten and twelve months of age, the number of eye-buds being 90 per each nitrogenous treatment. As the different plantings have shown similar trend in germination, the results of only the last period in which the planting material was of twelve months age are demonstrated in Fig. 4. It is quite evident from the increased rate of germination in the case of the planting material obtained from the higher nitrogenous treatments that the age of the planting material should not be the only criterion in its selection. From our knowledge of the reserve food materials on the process of germination and the initial growth of the shoot as discussed in section D, this variation in the rate of germination can be assigned to the differences in the chemical composition of the setts themselves. The most important constituents from the standpoint of the process of germination are apparently the carbohydrates and nitrogenous compounds. The carbohydrates are utilised in respiration or in other words for the transformation of potential to kinetic energy for pushing out the roots in the soil, the shoots above ground and carrying out the various activities of the seedlings. Miller [1931] in his

experiments with sun-flower seedlings has noted that one-fifth of the carbohydrates stored in the seed have been consumed for this purpose. Among the carbohydrates, hexoses are apparently the sugars utilised in the process, glucose being the most oxidisable one among them. Nitrogen is considered to be important in the anabolic activities of the growing bud, the lower forms of nitrogen being the most suitable for the purpose. In order, therefore, to find out the relative influence of carbohydrates and nitrogen on the rapidity of germination, the planting material from the series in the sand described above was analysed at start for glucose and amide nitrogen and these were put to the statistical test of correlation with the three weeks germination which was taken as the criterion for its rapidity. The results have given a positive correlation with amide nitrogen ($+0\cdot71\pm0\cdot063$), while no correlation is observed with glucose ($+0\cdot32\pm0\cdot115$). This lack of correlation with glucose would be considered rather surprising as it is against the consensus of opinion, which, due to the better performance of the immature canes as the planting material, generally associates glucose with the germinative capacity of the cane. A quantitative interpretation to this has been given by Evans [1936] who has actually shown a negative correlation ($-0\cdot62\pm0\cdot097$) between the reducing sugars and the number of days required for germination. He, however, has expressed the opinion that this relationship does not mean that the high reducing sugar is the cause of quick germination but should be considered only as a reliable index of the condition of the planting material with regard to its germinative capacity. Further light on this question has been thrown by the investigations of Das and his co-workers [1936] who have shown the association of high water content with high glucose content. In our manurial investigations to be described separately, we have also found similar relationship, and explanation as regards this disagreement in the correlations seems to lie in the variation in the conditions under which these studies have been carried out. All our germination experiments have been conducted under irrigation and therefore moisture is not a controlling factor. On the other hand, Evans has worked under dry conditions and the success of planting under these conditions will be chiefly dependent upon the soil moisture. It will be seen that under such conditions, the water content of the sett itself would count. The association of the increased quantity of water with the higher glucose content should thus be apparently an important factor in the correlation obtained by him. The importance of the water content of the sett is also visible from the improved germination he gets with soaking of setts in water or lime solution which is contrary to our findings. When the sett is soaked, it absorbs water, and therefore does not have to depend on the soil moisture to initiate its germination.

Fig. 4. Periodical germination of canes under varying manurial treatments (age of cane 12 months)

No such relationship has been observed between the amide nitrogen and water content of the cane. There are in fact indications of a tendency towards an increase of this nitrogen in the juice of the cane with the cessation of the vegetative activities (Table I). The high correlation observed in this case thus seems to be due to its direct influence on the rapidity of germination itself. This has received further confirmation by the favourable effect of the application of sulphate of ammonia in the furrows themselves at the time of planting. This results in its absorption through irrigational water and the analysis of the planting material shows an increase in its ammoniacal nitrogen content, which leads to the acceleration of the process of germination. (Table V and Figs. 1 and 2). Repeated field experimentation with sulphate of ammonia at the time of planting under varying conditions for three years has shown that while there has been almost invariably some improvement in the rate of germination, its influence is found to be significant under unfavourable conditions of either the seed material, climate or soil. On the other hand there appears to be no necessity of this treatment in the case of the combined favourable effect of these factors as the proper seed material, the presence of optimum temperatures and the retention of good tilth with the proper depth of planting. It is thus quite evident that the pre-requisite for the success of this treatment is the adverse nature of any one or more of these factors which appears to check the enzymic activities leading to the disintegration of protein nitrogen in assimilable lower forms. Out of these factors, it has been already shown that temperatures are predominant and in case they happen to be favourable during the period of germination, they mask to a great extent the adverse effect of the remaining two factors of the seed material as well as the soil.

V. Summary and conclusions

(1) The rapidity of germination is found to be predominantly influenced by the minimum temperatures which in their optimum condition even mask the effect of the chemical constituents of the planted material. Temperatures below 50°F. are definitely injurious.

(2) The advantages of the speed of germination have been observed to be two-fold. It leads to the increase in the final percentage germination. Secondly the shoots of the early germinated buds are vigorous and thus capable of withstanding the borer attack to a great extent.

(3) In order to get the optimum germination, it would be necessary to adjust the method of planting according to the soil type. While the existing method of pressing the sett by foot in the wet soil is found to be suitable for lighter soils, dry planting with slow irrigations improves the germination greatly in heavier soils.

(4) Buds with dry scales are found to be slow in their germinative capacity and the different proportions of these among the varieties appear to be one of the important reasons for the great deal of variability in the germinative capacity of the varieties. With the elimination of these dry-scaled buds from the planting material, germination in the varieties has been much more uniform,

(5) Although slightly higher rate of germination can be obtained in the case of single-budded setts due to the possibility of better selection, the crop in this case is poorer in the early stages of growth when compared to that from three-budded setts. The differences are, however, greatly minimised with the progress of growth, specially in the higher nitrogenous treatments.

(6) Age of the planting material should not be so much the criterion in the proper selection of setts as the chemical composition. Out of the two important chemical constituents required for germination, *viz.*, carbohydrates, mainly glucose, and soluble nitrogenous compounds, the latter has been found to be more important and has actually given a positive correlation, while no such relation has been found with the former. This lack of correlation with glucose seems to be due to our system of planting under irrigation. As a practical example of the importance of nitrogen in germination may be cited the beneficial effect of the application of sulphate of ammonia at the time of planting which is found to be significant especially under unfavourable conditions of soil, climate or seed material. It is thus evident that special seed areas heavily manured with nitrogenous top dressings and the application of sulphate of ammonia at planting will help in securing optimum germination.

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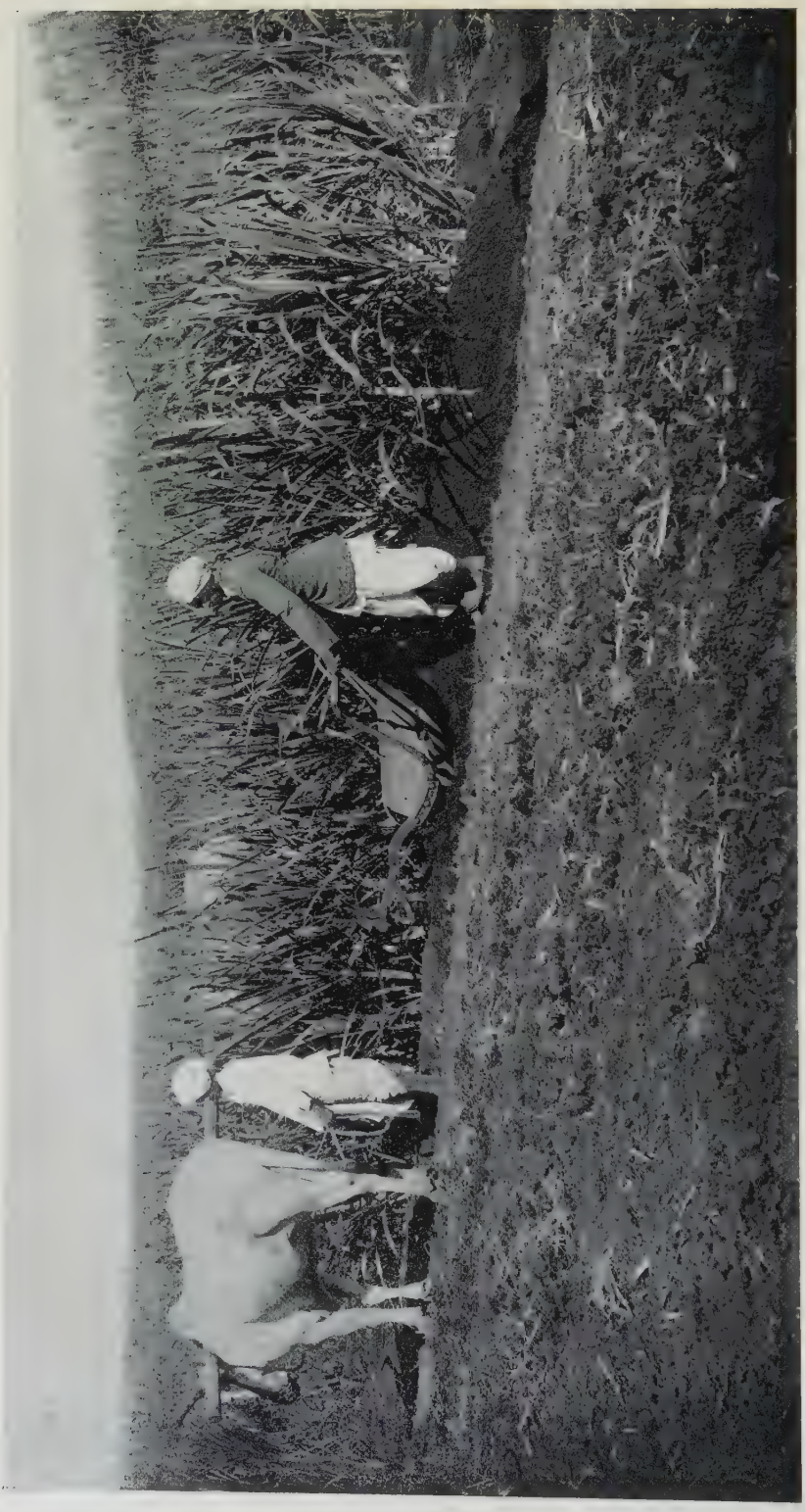

Earthing-up of cane with the *Sabul* plough

II. 'EARTHING UP' OF CANE

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(With Plates XIX and XX)

I. Introduction

'Earthing-up' or 'hilling', as it is also called in some countries, is an important operation in the cultivation of sugarcane, not only in India but in several other cane-growing tracts of the world. In the Deccan-canal tract, as also in most other places where sugarcane is grown under irrigation, the setts are planted in furrows, which are usually three and a half to four feet apart. As the cane plant grows and internodes are being formed above the ground level, earthing is done either two or three times or only once after five to six months of planting. In the case of partial earthing, the loose soil on the sides of the ridges is gradually put on either side of the growing plant by manual labour. The final earthing is generally done by the manual labour but can also conveniently be done by Sabul plough fitted with a special tail sheet attached to the mould-board for pressing the loose soil against the row of cane [Bom. Dept. Agric., 1929] (Plate XIX). Before this operation is done, however, all the dry leaves sticking to the canes are removed so as to expose the internodes likely to be covered with soil for facilitating the development of fresh roots from them. A heavy dose of nitrogenous top-dressings is then applied in the furrow near the base of the plant, as it becomes very difficult to manure the crop later. The Sabul plough breaks open the ridges between the furrows which are converted into ridges by getting the earth on either side against the canes, turning at the same time the old ridges into furrows.

The extent of this 'hilling' or earthing-up varies in different tracts. In places like Australia [Venkatraman, 1936] and Cuba [Earle, 1928] the cane crop is not appreciably earthed up so that by the harvest time the crop

* This scheme is partly subsidised by the Imperial Council of Agricultural Research.

stands practically on level ground, thus facilitating the harvesting operations by means of machinery. In the Deccan-canal tract, on the other hand, there is a tendency for a much higher earthing and this operation thus becomes very laborious requiring considerable labour and bullock power. The period of earthing of the major January-planted crop generally coincides with the sowing operations of the dry crops and as the labour is scarce at that time, the operation becomes costly. It is usually given by contract at the rate of Rs. 9 to Rs. 12 per acre. Although the Deccan-canal tract is known for its high tonnage of cane, the cost of production is also very high, being As. 6 to As. 7 per maund. Attempts are therefore directed towards exploring methods which would bring down this high cost and with this object a careful study of the process of earthing up was therefore undertaken.

The main advantage claimed for the process of earthing is its beneficial influence on the growth of cane. It is considered that the cutting off the cane roots during the process of earthing-up induces a fresh flush of feeding roots in the earthed-up zone, and this gives a fillip to the growth of the cane. There is, in fact, a consensus of opinion among sugarcane growers that failure or delay in this operation results in reduced yield. Incidentally, high earthing-up is also considered to give mechanical support to the canes, preventing them from lodging and also, to renew the irrigational system by opening up fresh furrows. The effect of the earthing-up would thus principally be a physiological one and therefore the developmental behaviour of the cane plant with and without earthing-up was carefully followed till harvest time. The results of these observations are embodied in the paper.

II. Experimental

(*a*) *Field experiments.*—These experiments were started on a small scale in 1935-36 with the variety POJ 2878. Of the twelve small-sized plots (0·73 cents each) under observation, six were earthed up and six were not. All the other treatments such as manuring, irrigation, etc., were similar in both cases. The results are given in Table I. It is interesting to note that the results of yields are quite the reverse of the general belief, the tonnage being actually higher in the case of the non-earthed plots, which can be attributed to the larger number of canes in this treatment. In weight per cane and in brix, however, there is a fall which seems to be due to the development of late tillers which would have otherwise been smothered up by the operation of earthing-up.

TABLE I

Earthing vs. *non-earthing*

Planted on 19-1-35, Harvest data (POJ 2878), Harvested on 11-1-36

Treatment	No. of canes per 3 ft.	Average weight per cane	Yield in tons per acre	Brix @17·5° c.
		lbs.		
Earthing	7·5	3·0	36·8	20·24
Non-earthing . . .	9·1	2·7	38·9	19·76

Encouraged by these results the experiment was repeated in replicated trials (plot size 1·74 cents) during the next two years, (1936-37 and 1937-38), there being four replicates of each treatment. The variety was the same, *viz.*, POJ 2878. Records of germination, tillering at earthing time, periodical growth, number and weight of canes at harvest, brix, sucrose and purity were maintained during both the years. The figures are given in Table II.

These figures clearly show that the germination as well as the tillering have been practically the same in both the treatments. In the number of canes at the harvest time, however, there is a distinct increase in the non-earthed treatment during 1936-37 and a slight one in 1937-38. This increase is mainly due to the development of the young shoots which escaped smothering in the non-earthed series as no further tillering was observed in this series after the earthing up of the other one. These tillers are, however, generally late-growing and may some time bring about a slight lowering of the brix or purity. The dissimilarity in the performance of tillers during the two seasons seems to be due to the different rates of germination in them. During the 1937-38 season, the rapidity of germination as indicated by three weeks counts (Table II, col. 1) led to early start in tillering, resulting in a large number of bigger shoots at earthing time, which reduced the loss of tillers by suppression with the process of earthing-up.

TABLE II

Earthing vs. *non-earthing*

(*Variety POJ 2878*)

Year	Treatment	Germination percentage at			No. of shoots at earthing per 3 ft.	No. of canes per 3 ft. at harvest	Percentage success	Weight per cane	Calculated yield in tons	Brix at 17·5°C.	Sucrose (per cent)	Purity (per cent)
		3 weeks	6 weeks	8 weeks								
		1	2	3	4	5	6	7	8	9	10	11
								lbs.				
1936-37 .	(*a*) Earthing . .	14·2	67·4	72·7	14·7	7·9	53·7	2·9	37·2	21·47	19·38	90·2
	(*b*) Non-earthing .	11·5	66·0	73·5	15·3	9·8	64·0	2·8	41·4	21·72	19·78	91·2
1937-38 .	(*a*) Earthing . .	24·7	66·9	70·3	15·0	9·0	60·0	2·9	43·0	21·79	19·63	90·1
	(*b*) Non-earthing .	27·3	68·0	71·0	15·5	9·9	63·9	2·8	44·8	21·79	19·23	88·2

In order to find out whether earthing-up does accelerate the growth to any extent, twenty-five random selected plants in each treatment were labelled at the time of earthing up and the heights of the millable cane recorded at harvest time after topping. The average height agreed very closely in both the cases, being 105·1 inches in the earthed-up and 105·0 inches in the other case. It would thus be seen that the slight fall in the average weight per cane (Table II, col. 7) in the non-earthed treatment is definitely due to the development of late tillers.

The final yield figures were tested for statistical significance (Table III). The experimental layout was a complex one including two other treatments. The data relating to earthing *vs.* non-earthing are alone given.

TABLE III

Yield data in lbs. per plot excluding ring (0·8 cent)
(Variety POJ 2878)

Replicate	1936-37		1937-38	
	Earthing	Non-earthing	Earthing	Non-earthing
I	687	777	752	809
II	739	699	764	858
III	710	813	860	805
IV	622	779	805	842
Mean	689	767	795	828
Critical difference for significance at $P = 0·05$ . .	83		75	

These results show a definite tendency towards increased yields in the non-earthed treatment almost approaching significance in 1936-37, while during 1937-38 the yields are almost similar in both the treatments. It is thus quite evident that absence of earthing does not in any way lead to the reduction in yield.

This experiment was also tried on a field scale. A cane plot 80 cents of POJ 2878 was divided into four blocks of 20 cents each, two of which were earthed-up as usual and the other two were left non-earthed. The yields of the main plots excluding the ring calculated in tons per acre are given in Table IV.

TABLE IV

Yield in tons per acre

(*Variety POJ 2878*)

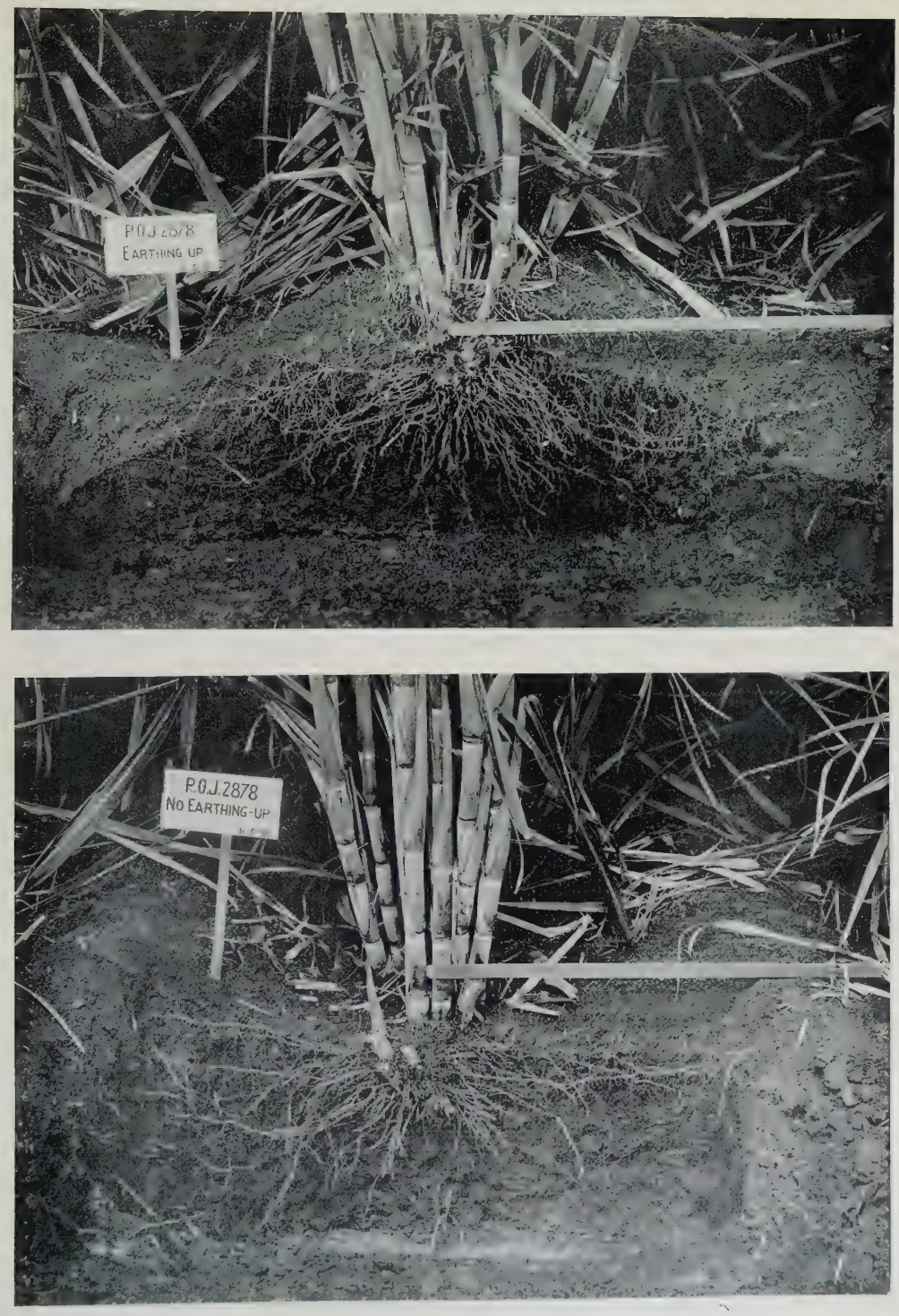
Planted on 9-2-37 Harvested on 6, 7 and 8-2-38

Replicate	Earthing	Non-earthing
I	36·8	40·0
II	39·2	42·4
Mean	38·0	41·2
Brix @17·5°C.	22·5	22·4

There is an increase of 8·4 per cent in the yield of non-earthed crop without any fall in the brix.

It may be pointed out here that the season (1937-38) was characterised by a heavy downpour of about 8 in. of rain accompanied by a cyclone during September, which caused greater lodging in the non-earthed cane, especially under exposed conditions. In spite of this, there has not been any appreciable fall in the brix or purity in this variety (Tables II and IV).

(*b*) *Root studies.*—With a view to find out if there are any advantages to the root-system by the process of earthing-up, as are usually claimed, careful dissections of the roots of stools were made under both the treatments (Plate XX). It will be seen that there is practically very little difference in the two treatments, except that in the case of the earthed-up stools the fine roots formed after the last dose of nitrogenous top-dressing are found in the earthed-up zone; while in the other case they are restricted to the surface layer of the soil forming a thick network. The difference in the functioning of the roots was studied three and a half months after the operation of earthing



Root system of cane (POJ 2878) with and without earthing

by an analysis of the exudates collected from canes under both the conditions and also after removing the fresh surface roots formed after earthing. The results of these studies are given in Table V.

TABLE V

Exudation studies

($3\frac{1}{2}$ months after earthing-up)

Treatment	Quantity of sap exuded per cane in 24 hours	Absorption per cane per day			
		Nitrates	Ammonia	K_2O	P_2O_5
	(c.c.)	mg.	mg.	mg.	mg.
1. Non-earthing .	63	0·025	0·19	2·63	0·74
2. Earthing . .	36	0·024	0·12	2·55	0·66
3. Earthing with roots in the earthed zone removed . .	40	0·021	0·064	2·83	0·50

These figures clearly show that the root-system in the case of earthing-up remains mainly as surface feeder, while in the absence of earthing it develops, in addition, a capacity to tap deeper layers as well. The large quantity of exudates obtained in the non-earthed treatment also clearly indicates that the crop is capable of taking its water requirement from lower layers and would thus require less irrigational water than in the other case. In fact owing to the slow silting of the furrows with irrigation, the non-earthed crop actually receives less water at every irrigational turn than the earthed-up one where new furrows are opened with the operation of earthing-up, thus renewing the system afresh. This reduction in the quantity of water is not found to produce any deleterious effect on crop growth. There is thus an actual saving of water in the non-earthed treatment which is estimated to be between 10 to 15 per cent. The analysis of the exudate further shows all the mineral constituents to be more available in this treatment than in the other one and it is thus quite evident that the functioning of the root-system is not in any way improved by the operation of earthing up.

III. CONCLUSIONS

The prevalent idea among the sugarcane growers about the necessity of earthing in order to accelerate growth for the improvement in yield is found to be quite untenable on actual experimentation. On the contrary, the treatment which was not earthed has shown a definite tendency towards

higher yields. This can be mainly ascribed to the presence of larger number of millable canes at harvest time in this treatment owing to the development of late tillers which are otherwise smothered by the operation of earthing. Root investigations have also shown that, with the operation of earthing, the root-system is actually impaired as it remains mainly as a surface feeder, while in the non-earthed treatment, it develops a capacity to tap deeper layers as well. It is thus quite evident that the general belief about the beneficial effect of earthing on growth is based on a misconception as the impetus to growth observed after this operation appears to be entirely due to the nitrogenous top-dressing of the crop which immediately precedes it.

The high earthing as practised in the canal tract does, no doubt, act as a mechanical support, especially to the lodging varieties. It is not, however, very important for the erect types which now occupy a major area in this tract. It is only in the case of cyclonic weather that lodging appears in these varieties, specially under exposed conditions and this is observed to be more in the case of the non-earthed treatment. This weather is, however, generally met with in late September or October and lodging at this period is not found to adversely affect the yield or the brix. Another advantage of irrigational facilities claimed for this operation is found to be actually a disadvantage, as the opening of fresh deep furrows leads to the application of higher delta of water than the crop requirement, resulting in the wastage of canal water which is brought to this tract at a very high cost to the Government. It has been observed that in the case of four-feet spacing between furrows at the time of planting as recommended in the standard Manjri method no difficulty in watering is ever experienced till harvest time, the furrows remaining sufficiently deep to accommodate the water required by the crop.

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THE EXCHANGE OF MOISTURE BETWEEN PLANT MATERIALS AND THE ATMOSPHERE

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(With four text-figures)

I. Introduction

Ramdas and Katti [1934; 1935; 1936] have discussed, in a series of papers, the phenomenon of the diurnal exchange of moisture during the clear season between a dry soil surface when it contains only hygroscopic moisture and the air layers near the ground. They have shown that the soil has its maximum moisture content at the minimum temperature epoch and its minimum moisture content at the maximum temperature epoch. From the morning after sunrise up to the afternoon, the soil surface gives up moisture by evaporation to the air layers above, but thereafter, until the next morning, it desiccates the air layers by re-absorbing almost all the moisture lost. It was also shown that the intensity of this moisture exchange is greatest in the black cotton soil of the Deccan and least in the alluvial soil of the Indo-Gangetic plains.

Much work has been done by various workers* on the hygroscopic properties of textiles like cotton, silk, wool, etc. Mention may be made of the investigations of Wilson and Fuwa [1922] on the absorption of moisture by a variety of materials including some plant materials like tobacco, wheat bread, flour, etc., when exposed to air of different relative humidities. Nazir Ahmad [1933] studied the seasonal variation of the moisture content of bales of cotton stored in godowns. He showed that cotton absorbed moisture during the monsoon season but lost it again during the dry season. Diatlova [1935] found that there is a diurnal variation in the moisture content of grain and straw of spring wheat ready to be harvested, the highest moisture content occurring at 5 A.M. and the lowest moisture content between 1 and 4 P.M.

During the clear season of 1937-38, experiments, similar to those in the case of the soils, were made on the diurnal variation in the moisture content of various plant materials, at the Central Agricultural Meteorological Observatory at Poona. The clear season is characterised by a large diurnal range of

*For references to literature on this subject see Chapter XII of " The absorption of gases and vapours by solids " by J. W. McBain (Routledge and Sons, Ltd., 1932).

temperature, cloudless skies and comparatively low relative humidity during the day. A short note stating some of the results obtained has been published elsewhere [Ramdas and Mallik, 1938] ; in the present paper the results are discussed more fully.

II. Materials and methods

The materials used for this study were :

(*a*) Black cotton soil of Poona.
(*b*) Wheat grain.
(*c*) Paddy grain.
(*d*) *Bajri* grain.
(*e*) *Jowar* grain.
(*f*) *Jowar* leaf (cut into pieces).
(*g*) *Jowar* leaf (entire).
(*h*) *Jowar* stalk (cut into pieces).

All the materials were perfectly dry in the agronomical sense. The specimens were exposed to the atmosphere in small vessels embedded in the soil and their weights determined at desired intervals.

The various conditions to which the specimens were exposed in different experiments were :

(*i*) ' Open and exposed to solar radiaton '
(*ii*) ' Open but shaded from solar radiation ' and
(*iii*) ' In the Stevenson screen at ground level. '

Two sets of experiments were performed. In one set, the specimens were weighed twice daily at 8 A.M. and 4 P.M. consecutively for six days ; this was done with the materials exposed to ' open in sun ' and again with specimens exposed inside a Stevenson screen at ground level. In the other set, on some selected days, the diurnal variation in weights of the different materials was studied by taking two-hourly observations. In every case, simultaneous records of temperature and humidity of the air layers were obtained with an Assmann Psychrometer.

III. Statement of results

A. Maximum and minimum moisture content during the period 23rd November 1937 to 28th November 1937

(*a*) A set of specimens was exposed to the atmosphere in the sun. The specimens were weighed daily at 8 A.M. and 4 P.M. for six days. The values of atmospheric humidtiy at the same hours were also calculated from the dry bulb and wet bulb readings of the Assmann Psychrometer. Table I gives the weights in grams of these materials at 8 A.M. and 4 P.M. from the 23rd to the 28th November 1937.

At the bottom of Table I is given the mean weights of the specimens at 8 A.M. and 4 P.M. as well as the difference between the mean 8 A.M. and mean 4 P.M. weights expressed as percentages of the mean values for the whole day. The results are shown graphically in Fig. 1.

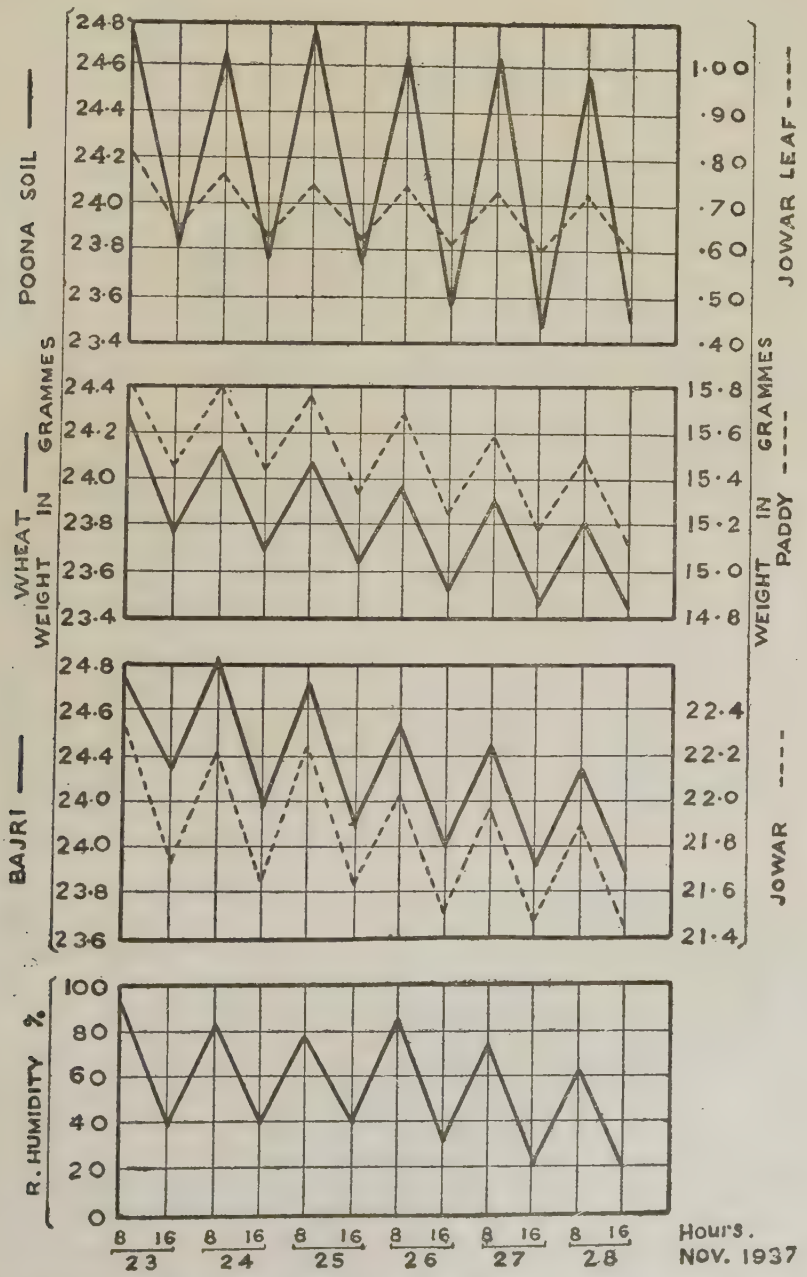

FIG. 1. Weights of samples of Poona soil, *jowar* leaf, wheat, paddy, *bajri* and *jowar* exposed to the open in sun, and values of relative humidity at 0800 hrs. and 1600 hrs. daily from 23rd to 28th November 1937.

(*b*) The above experiment was repeated in January 1938 but this time the specimens were exposed inside a Stevenson screen at ground level.

Table II gives the weights in grams of the materials at 8 A.M. and 4 P.M. from the 17th to the 22nd January 1938.

At the bottom of Table II are given the mean weights of the samples at 8 A.M. and 4 P.M. as well as the differences between these mean 8 A.M. and 4 P.M. weights expressed as percentages of the mean weights for the day. The same results are shown graphically in Fig. 2.

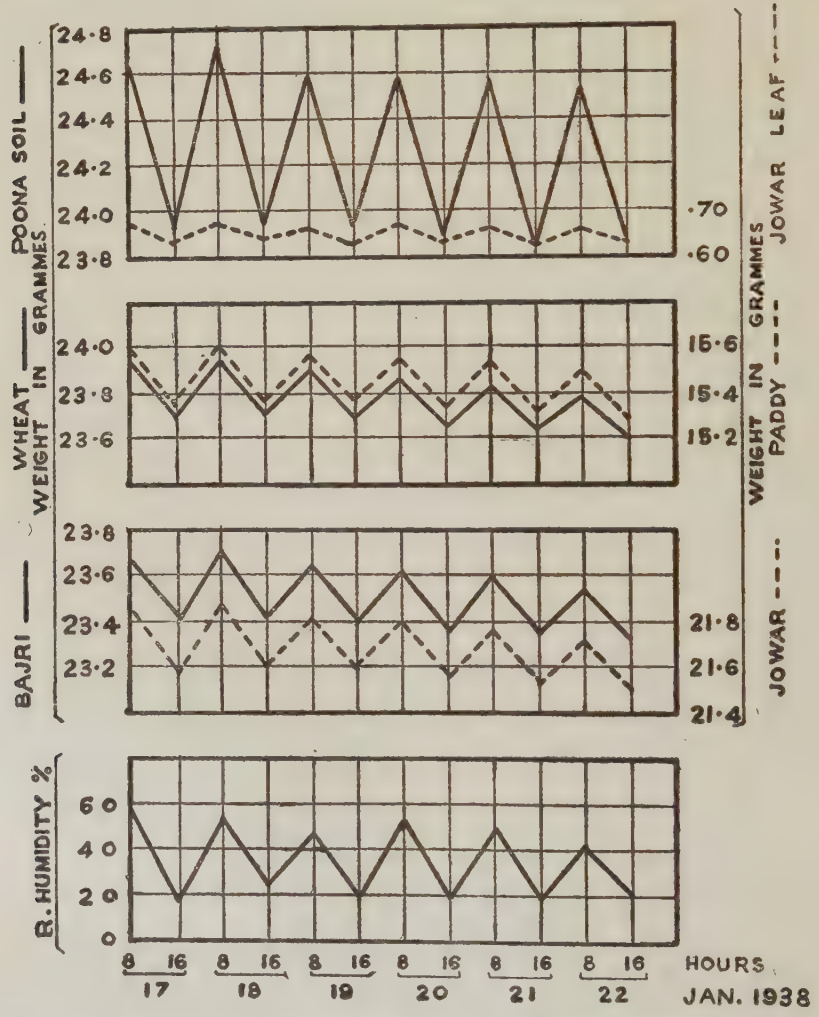

FIG. 2. Weights of samples of Poona soil, *jowar* leaf, wheat paddy, *bajri* and *jowar* exposed inside a Stevenson screen at ground level, and values of relative humidity at 0800 hrs. and 1600 hrs. daily from 17th to the 22nd January 1938.

TABLE I

Open (maximum and minimum weights in grms.)

Date	Time	Weight in grams						Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg)	Humidity (per cent)
		Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)				
23rd November 1937 .	8 A.M.	24·7343	24·2625	15·8561	24·7349	22·3078	0·8050	10·8	10·0	8·8	91
	4 P.M.	23·8135	23·7737	15·3525	24·3445	21·7319	0·6536	29·8	20·3	13·1	42
24th November 1937 .	8 A.M.	24·6641	24·1430	15·7957	24·8228	22·1974	0·7686	9·8	8·5	7·7	84
	4 P.M.	23·7535	23·6925	15·4309	24·2100	21·6536	0·6364	30·4	20·3	12·8	39
25th November 1937 .	8 A.M.	24·7675	24·0859	15·7743	24·7088	22·2468	0·7440	11·8	9·8	8·1	78
	4 P.M.	23·7307	23·6339	15·3425	24·0970	21·6311	0·6293	29·4	19·8	12·5	41
26th November 1937 .	8 A.M.	24·6605	23·9699	15·6648	24·5328	22·0029	0·7263	10·5	9·2	8·1	85
	4 P.M.	23·5531	23·5215	15·2550	24·0126	21·5196	6·6194	30·2	19·0	10·9	34
27th November 1937 .	8 A.M.	24·6304	23·9115	15·5846	24·4401	21·9651	0·7178	10·2	8·0	6·9	74
	4 P.M.	23·4561	23·4741	15·1915	23·9345	21·4787	0·6006	31·5	17·2	7·6	22
28th November 1937 .	8 A.M.	24·5957	23·8266	15·5077	24·3495	21·8984	0·7150	11·5	8·0	6·3	62
	4 P.M.	23·4323	23·4163	15·1067	23·8735	21·4534	0·5926	33·5	17·5	7·0	18
Mean weight . .	8 A.M.	24·6754	24·0332	15·6972	24·5983	22·1031	0·7461	..	..	7·6	79
	4 P.M.	23·6232	23·5853	15·2800	24·0787	21·5747	0·6219	..	..	10·7	33
Difference between the mean values at 8 A.M. and 4 P.M. expressed as percentages of the mean of the day		4·36	1·88	2·69	2·14	2·42	18·16	..	..	33·88	82·14

TABLE II

Inside Stevenson screen at ground level (maximum and minimum weights in grms.)

Date	Time	Weight in grams						Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg.)	Humidity (per cent)
		Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)				
17th January 1938 .	8 A.M.	24·6746	23·9379	15·6000	23·6635	21·8378	0·6688	20·5	15·2	10·3	57
	4 P.M.	23·9209	23·6999	15·3583	23·3947	21·5838	0·6333	32·5	17·2	7·1	19
18th January 1938 .	8 A.M.	24·7209	23·9535	15·6143	23·7055	21·8842	0·6736	19·5	13·8	9·0	53
	4 P.M.	23·9477	23·7099	15·3713	23·4211	21·6086	0·6352	31·5	17·8	8·4	24
19th January 1938 .	8 A.M.	24·5957	23·9055	15·5675	23·6359	21·8194	0·6612	20·0	13·2	8·0	46
	4 P.M.	23·9449	23·7031	15·3659	23·4047	21·5950	0·6336	32·0	16·5	6·3	18
20th January 1938 .	8 A.M.	24·5813	23·8621	15·5479	23·6155	21·7998	0·6660	19·8	14·0	9·1	53
	4 P.M.	23·8997	23·6591	15·3351	23·3665	21·5602	0·6340	31·5	16·5	6·6	19
21st January 1938 .	8 A.M.	24·5597	23·8287	15·5279	23·5959	21·7734	0·6644	19·2	13·0	8·1	49
	4 P.M.	23·8701	23·6391	15·3187	23·3527	21·5410	0·6304	32·5	16·8	6·5	18
22nd January 1938 .	8 A.M.	24·5401	23·7843	15·4987	23·5379	21·7230	0·6644	20·5	13·0	7·5	41
	4 P.M.	23·8549	23·6103	15·2853	23·3324	21·5106	0·6288	31·8	17·2	7·4	21
Mean weight . .	8 A.M.	24·6121	23·8787	15·5594	23·6257	21·8063	0·6666	..	..	8·67	50
	4 P.M.	23·9063	23·6702	15·3394	23·3787	21·5665	0·6326	..	..	7·04	20
Difference between the mean values at 8 A.M. and 4 P.M. expressed as percentages of the mean of the day		2·91	0·88	1·42	1·05	1·11	5·23	..	..	..	..

B. Diurnal variation in the weights of specimens (due to exchange of moisture with the air layers near the ground)

(*i*) Specimens were kept in the open exposed to sun's rays and weighed every two hours from the morning of one day to the morning of the next day on two occasions, *viz.*, 17th to 18th and 27th to 28th November 1937. Dry bulb and wet bulb temperatures of the air just above the specimens were also recorded by means of an Assmann Psychrometer.

Tables III and IV give the weights of the materials expressed as percentages of the mean weight as well as the dry bulb and wet bulb readings and the calculated vapour pressure and relative humidity values at two-hourly intervals.

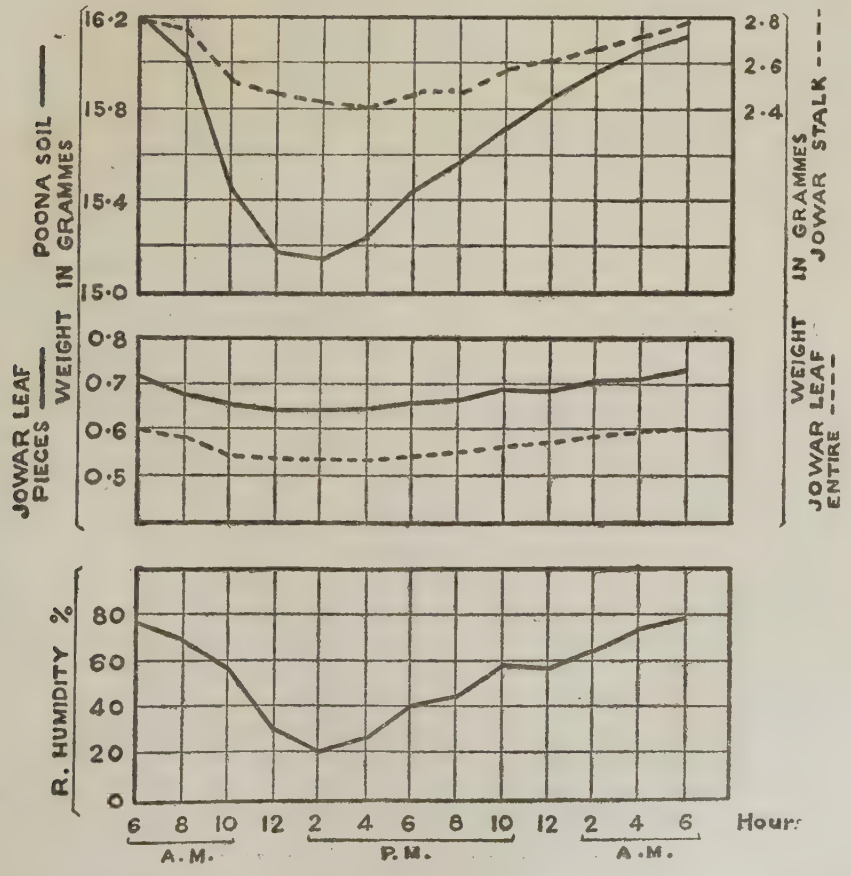

FIG. 3. Hourly variation of the weights of samples of Poona soil, *jowar* stalk, *jowar* leaves cut to pieces and *jowar* leaf entire, exposed to open in sun, and the relative humidity from 0600 hrs. on 17th November to 0600 hrs. on 18th November 1937.

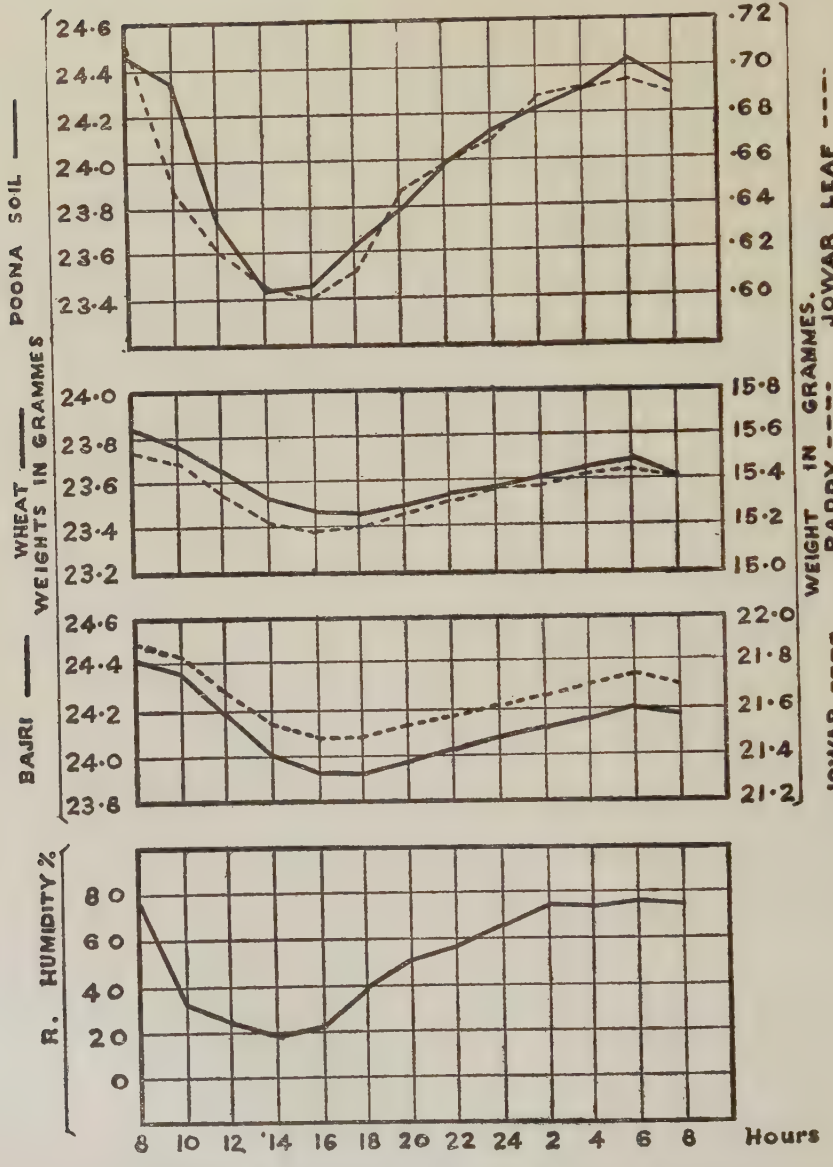

FIG. 4. Hourly variation of the weights of samples of Poona soil, *jowar* leaf, wheat, paddy, *bajri* and *jowar* exposed to open in sun and of the relative humidity from 0800 hrs. on 27th November to 0800 hrs. on 28th November 1937.

TABLE III

Exposed to open in sun (two-hourly observation; actual weights expressed as percentages of mean weight)

Date	Time (hrs.)	Soil	*Jowar* stalk	*Jowar* leaf cut into pieces	*Jowar* leaf, entire	Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg.)	Relative humidity (per cent)
17th November 1937.	0600	103·3	107·6	105·9	109·5	9·8	7·8	6·9	76
Do.	0800	102·1	105·6	100·5	102·8	13·0	10·0	7·7	69
Do.	1000	98·5	97·6	96·3	95·8	21·8	16·1	10·9	56
Do.	1200	96·7	95·6	94·9	94·4	31·4	19·1	10·4	30
Do.	1400	96·5	93·9	94·9	94·1	36·0	19·8	9·2	21
Do.	1600	97·1	93·1	94·9	94·1	30·8	17·8	8·8	26
Do.	1800	98·4	95·3	96·6	95·5	24·0	15·5	9·0	40
Do.	2000	99·2	95·6	97·7	96·9	18·8	12·2	7·4	45
Do.	2200	100·2	99·5	101·1	99·3	14·2	10·0	7·1	59
Do.	2400	101·2	101·3	101·5	101·3	14·0	9·8	7·0	58
18th November 1937.	0200	101·6	103·0	103·6	103·0	12·5	9·2	7·1	65
Do.	0400	102·4	104·8	105·1	104·7	10·8	8·5	7·2	74
Do.	0600	102·8	107·1	106·9	108·7	9·9	8·0	7·2	79
100 per cent =		15·6926 grms.	2·5861 grms.	0·6803 grms.	0·5739 grms.				
Range of variation (per cent)		6·8	14·5	12·0	15·4				

TABLE IV

Exposed to open in sun (two-hourly observations; actual weights expressed as percentages of the mean weight)

Date	Time (hours)	Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)	Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. (of Hg)	Humidity (per cent)
27th November 1937.	0800	101·8	101·0	101·3	101·2	101·2	108·5	15·5	13·0	10·0	76
Do.	1000	101·5	100·7	100·9	101·0	100·9	98·7	28·0	17·2	9·3	33
Do.	1200	98·5	100·2	100·0	100·3	100·2	94·5	31·5	18·0	8·7	25
Do.	1400	97·6	99·7	99·2	99·6	99·5	92·4	34·2	18·2	7·7	19
Do.	1600	97·7	99·4	98·9	99·2	99·2	91·5	31·5	17·2	7·6	22
Do.	1800	98·4	99·4	99·0	99·2	99·2	93·2	22·5	14·2	8·0	39
Do.	2000	99·1	99·5	99·4	99·4	99·5	98·5	16·7	11·2	7·2	51
Do.	2200	99·9	99·7	99·7	99·6	99·6	100·3	14·0	9·8	7·0	58
Do.	2400	100·4	99·9	100·0	99·8	99·8	102·1	12·2	9·0	7·0	66
28th November 1937.	0200	100·8	100·0	100·2	100·0	100·0	104·6	10·5	8·2	7·0	74
Do.	0400	101·3	100·2	100·4	100·1	100·2	105·1	9·8	7·6	6·7	74
Do.	0600	101·7	100·3	100·6	100·3	100·5	105·7	9·0	7·0	6·5	76
Do.	0800	101·3	100·0	100·5	100·3	100·2	104·8	14·5	12·0	9·3	75
100 per cent =		24·6730 grms.	23·6109 grms.	15·3831 grms.	24·1116 grms.	21·6496 grms.	0·6563 grms.				
Range of variation (per cent)		4·2	1·6	2·4	2·0	2·0	17·0				

(*ii*) The above experiment was repeated changing the condition of exposure. The specimens were exposed within a Stevenson screen at ground level. Table V gives the two-hourly weights expressed as percentages of the mean weight for the day and the dry bulb, wet bulb, vapour pressure and humidity values.

TABLE V

Inside Stevenson screen at ground level (two-hourly observations, actual weights expressed as percentages of the mean weight)

Date	Time (hours)	Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)	Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg)	Humidity (per cent)
11th January 1938.	0800	100·8	100·2	100·4	100·3	100·3	100·2	14·5	9·2	6·1	49
Do.	1000	100·8	100·3	100·3	100·3	100·3	98·2	23·5	13·8	7·0	32
Do.	1200	100·0	100·2	100·1	100·2	100·1	98·1	27·8	15·2	6·7	24
Do.	1400	99·2	99·9	99·7	99·9	99·9	98·1	32·5	17·2	7·1	19
Do.	1600	98·8	99·8	99·5	99·7	99·6	97·8	30·5	17·0	7·8	24
Do.	1800	98·6	99·6	99·3	99·5	99·4	97·7	28·2	17·2	9·2	32
Do.	2000	99·1	99·6	99·5	99·6	99·5	98·7	24·5	15·8	9·1	40
Do.	2200	99·6	99·7	99·6	99·7	99·6	99·8	20·5	13·8	8·5	47
Do.	2400	99·9	99·9	99·9	99·8	99·8	100·4	17·5	12·2	8·0	53
12th January 1938.	0200	100·2	100·	100·2	100·1	100·0	101·3	14·8	10·5	7·4	58
Do.	0400	100·5	100·2	100·4	100·2	100·2	102·9	12·2	9·2	7·2	68
Do.	0600	101·2	100·3	100·6	100·4	100·4	103·4	12·0	10·0	8·2	78
Do.	0800	101·2	100·3	100·6	100·4	100·7	103·5	14·2	9·8	6·9	57
100 per cent =		24·2642 grms.	23·7510 grms.	15·4192 grms.	23·4734 grms.	21·6658 grms.	0·6559 grms.				
Range of variation (per cent)		2·6	0·7	1·3	0·9	1·3	5·8				

(*iii*) In this experiment the materials were exposed to open but shaded from the sun.

Table VI gives the two-hourly weights expressed as percentages of the mean weight of the day as well as the dry bulb and wet bulb temperatures and the calculated vapour pressure and relative humidity values.

TABLE VI

Open (in shade) (two-hourly observations ; actual weights expressed as percentages of the mean weight)

Date	Time (hours)	Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)	Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg)	Humidity (per cent)
4 thMarch 1938	0800	100·3	100·5	100·0	100·2	100·0	103·0	27·1	16·4	8·6	32
Do.	1000	99·1	99·9	99·7	99·7	99·8	101·7	31·7	17·4	7·8	22
Do.	1200	98·0	99·5	99·6	99·3	99·6	98·3	33·5	17·1	6·4	16
Do.	1400	98·0	99·5	99·5	99·2	99·4	95·4	38·5	18·0	5·2	10
Do.	1600	97·7	99·4	99·4	99·0	99·3	95·1	38·0	18·0	5·5	11
Do.	1800	98·3	99·4	99·5	99·3	99·5	96·5	33·0	20·2	11·4	30
Do.	2000	99·6	99·7	99·7	99·6	99·6	96·7	30·3	20·0	12·4	38
Do.	2200	100·6	99·7	99·9	99·8	99·8	97·0	28·0	18·5	11·2	40
Do.	2400	101·1	100·1	100·4	100·2	100·1	99·4	24·5	16·3	9·8	43
5th March 1938	0200	101·5	100·3	100·5	100·6	100·5	101·5	21·7	14·5	8·8	45
Do	0400	102·0	100·6	100·7	101·0	100·8	104·0	19·5	13·3	8·3	49
Do.	0600	102·4	100·8	100·8	101·2	101·1	106·5	17·0	11·3	7·2	50
Do.	0800	101·3	100·5	100·2	100·8	100·4	104·5	23·4	17·3	11·8	55
100 per cent=		24·2104 grms.	23·2003 grms.	25·0679 grms.	22·8563 grms.	21·0889 grms.	0·2110 grms.				
Range of variation (per cent)		4·7	1·4	1·4	2·2	1·8	11·4				

(*iv*) In this experiment two sets were exposed simultaneously, one in the open with the sun's rays falling on the specimens while the other was exposed in the open but shaded from the sun. The specimens were weighed at two-hourly intervals and the readings of the dry bulb and wet bulb temperatures recorded at the same time.

Tables VII and VIII give the diurnal variation in the weights expressed as percentages of the mean weights for the whole day as well as the dry bulb, wet bulb, vapour pressure and relative humidity values.

TABLE VII

Exposed to the open in sun (two-hourly observations ; actual weights expressed as percentages of the mean weight)

Date	Time (hrs.)	Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)	Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg)	Humidity (per cent
2nd May 1938	0800	105·9	102·5	103·2	104·2	102·7	124·1	36·5	19·0	7·7	17
Do.	1000	103·4	101·5	101·5	101·2	100·7	100·4	38·5	19·5	7·5	15
Do.	1200	97·0	99·7	99·3	99·8	99·8	75·7	43·5	20·5	6·6	10
Do.	1400	94·4	99·2	98·6	98·8	99·2	73·5	43·0	20·0	6·0	9
Do.	1600	94·8	98·8	98·2	98·0	98·7	71·6	42·0	21·2	8·5	14
Do.	1800	96·1	98·7	98·3	97·9	98·6	79·6	35·5	19·5	9·0	21
Do.	2000	97·8	99·0	99·0	98·5	98·9	91·3	31·5	21·5	14·2	41
Do.	2200	99·0	99·3	99·4	99·0	99·2	98·4	28·0	23·0	18·6	65
Do.	2400	100·7	99·5	99·7	99·6	99·5	104·4	25·2	24·0	21·8	91
3rd May 1938	0200	101·7	100·0	100·3	100·2	100·3	114·8	23·0	21·0	20·0	95
Do.	0400	102·5	100·4	100·6	100·7	100·7	120·3	21·5	19·5	18·4	96
Do.	0600	103·3	100·7	100·9	101·1	101·0	123·3	20·5	18·5	15·0	83
Do.	0800	103·2	100·7	100·9	101·0	100·9	123·0	34·5	25·0	19·0	46
100 per cent =		23·0254 grms.	26·5556 grms.	25·6193 grms.	20·5482 grms.	19·3589 grms.	1·3618 grms.				
Range of variation (per cent)		11·5	3·8	5·0	6·3	4·1	52·5				

TABLE VIII

Exposed to the open but always in shade (two-hourly observations ; actual weights expressed as percentages of the mean weight)

Date	Time (hrs.)	Soil	Wheat (grain)	Paddy (grain)	*Bajri* (grain)	*Jowar* (grain)	*Jowar* (leaf)	Dry bulb (°C.)	Wet bulb (°C.)	Vapour pressure (mm. of Hg)	Humidity (per cent)
2nd May 1938	0800	101·9	101·0	101·3	101·4	101·4	106·0	34·5	18·5	8·0	19
Do.	1000	100·2	100·3	100·2	100·5	100·6	99·4	37·5	18·2	6·0	12
Do.	1200	98·3	99·9	99·1	99·6	99·8	98·1	40·8	18·0	4·1	7
Do.	1400	98·0	99·4	98·8	99·2	99·5	93·6	41·0	19·8	6·7	11
Do.	1600	98·2	99·2	98·8	99·1	99·1	98·6	39·5	21·5	10·2	19
Do.	1800	98·8	99·1	99·0	99·0	99·0	99·0	36·5	20·6	10·2	22
Do.	2000	99·2	99·2	99·3	99·3	99·3	99·5	30·0	18·5	10·2	32
Do.	2200	99·6	99·5	99·6	99·6	99·6	99·9	26·5	22·7	18·8	72
Do.	2400	100·0	99·7	100·1	99·9	99·8	100·5	25·0	24·0	21·9	92
3rd May 1938	0200	100·6	100·2	100·5	100·2	100·2	101·0	22·5	22·0	19·6	96
Do	0400	101·3	100·5	100·9	100·6	100·4	101·3	21·5	21·0	18·4	96
Do.	0600	102·0	101·0	101·3	100·9	100·8	101·8	20·5	18·5	15·0	83
Do.	0800	101·8	100·9	101·2	100·8	100·5	101·5	32·0	28·3	23·2	65
100 per cent =		22·8402 grms.	20·5787 grms.	24·3880 grms.	24·0255 grms.	22·7844 grms.	1·1888 grms.				
Range of variation (per cent)		4·0	1·9	2·5	2·4	2·4	12·4				

IV. Discussion

A. Explanation of the results

From the foregoing account it emerges that plant materials exchange moisture with the air layers surrounding them just as the soils do. The curves of diurnal exchange of mositure by plant materials are somewhat similar to that of the soil ; both the soil as well as the plant materials lose moisture from morning till afternoon, but regain during the afternoon and night almost all the moisture lost during the day. There is also a striking similarity in the form of the curves of soil and plant materials to that of relative humidity. In other words, as the relative humidity of the air decreases, soil and plant materials tend to give up moisture to the air layers, but when the relative humidity of the air increases, they desiccate the atmosphere by absorbing moisture from the air layers surrounding them.

B. Maximum and minimum moisture content

The epochs of maximum and minimum moisture contents vary slightly in the different cases. In soils the epoch of minimum moisture content coincides with the maximum temperature epoch while the maximum moisture content occurs at the same time as the minimum temperature epoch. In the case of plant materials, except when the materials are exposed inside a Stevenson screen, the maximum moisture content occurs about the same time as the minimum temperature epoch, *i.e.*, at about 6 A.M. The loss of weight from 6 A.M. to 8 A.M., however, is not so well marked as in the case of soil. While the soil starts losing moisture from 6 A.M., the loss of weight from 6 to 8 A.M. is generally not very striking in the case of plant materials. Inside a Stevenson screen the intensity of the phenomenon is less and there is a general lag ; the plant materials attain their maximum weight only at 8 A.M., and not at 6 A.M. as in the other cases when exposed to the open.

The minimum moisture content of plant materials, unlike soils, does not occur exactly at the maximum tem perature epoch. In this respect, the plant materials studied show difference even amongst themselves, some showing the minimum weight at about 2 P.M. as the soil does, while others go on losing weight till as late as 6 P.M. It is seen that, in general, plant materials attain their minimum moisture content a little later than the soil, materials like seed grains showing a greater lag than do specimens of dry *jowar* stalk or leaf. Thus, the lag, which is slightly noticeable at the maximum moisture epoch, becomes strikingly apparent (4 hours sometimes) during the minimum moisture epoch. The exchange of moisture between a soil in a finely divided state and the air is more rapid than in the case of the plant materials. In the case of plant materials the process is not so rapid because of the cell walls through which the water vapour has to pass in getting in or going out. The seed-coat of the grains is still less permeable to water vapour than the dry cells of *jowar* leaf or stalk and hence the lag in the epochs of maximum and minimum moisture content is more in the case of the grains than in the case of dry *jowar* leaves and stalks.

C. Diurnal variation in moisture content under different conditions

The difference between the maximum and minimum weights, or the amplitude of variation expressed on percentage basis, is shown in Table IX.

TABLE IX

The amplitude of variation in weight (or the maximum weight minus the minimum weight expressed as a percentage of the mean weight), on different days and under different conditions of exposure

Materials	17th November 1937, exposed to open, in sun	27th November 1937, exposed to open, in sun	11th January 1938, exposed inside S.S. at ground level	4th March 1938, exposed to open, shaded from sun	2nd May 1938, exposed to open, in sun	2nd May 1938, exposed to open, shaded from sun
	1	2	3	4	5	6
1. Black cotton soil.	6.8	4.2	2.6	4.7	11.5	4.0
2. Wheat grains	..	1.6	0.7	1.4	3.8	1.9
3. Paddy grains	..	2.4	1.3	1.4	5.0	2.5
4. *Bajri* grains	..	2.0	0.9	2.2	6.3	2.4
5. *Jowar* grains	..	2.0	1.3	1.8	4.1	2.4
6. *Jowar* leaf cut into pieces	12.0	17.0	5.8	11.4	52.5	12.4
7. *Jowar* leaf entire	15.4					
8. *Jowar* stalk cut into pieces	14.5					

Table IX brings out the following points :—

(1) The diurnal variation is greatest in dry plant materials like *jowar* leaf and stalk and least in the seed grains, while soil occupies an intermediate position in this respect.

(2) The diurnal variation is maximum when the samples are exposed to the sun, and minimum when they are exposed in a Stevenson screen ; when exposed in the open but shaded from sun, the values are intermediate between those in the above two cases.

(3) The effect of season can be studied by comparing column 2 with column 5 as well as column 4 with column 6 where the same materials were exposed to identical conditions in different parts of the year. It becomes clear from the above comparison that the exchange of moisture between soil and plant materials and the air layers surrounding them is greater in the hotter than in the colder parts of the year.

(4) The effect of insolation is clearly brought out by a comparison of columns 5 and 6. The conditions of exposure were similar in all respects except

that in one case the direct insolation was out off. It is seen that just by cutting off the insolation the amplitude of the variation in weights is reduced by about 50 per cent.

Significance of the above results in agricultural practice

The fact that dry plant materials lose moisture during the day and regain during the night may have a bearing on agricultural marketing. From what has been said it is evident that a difference between the maximum and minimum weights (for materials like dry *jowar* stalk and leaf) equivalent to about 10-15 per cent of the mean weight for the day is not unusual when the material is fully spread out. In actual practice grain and fodder are handled in bulk and it is necessary to find out how the diurnal variation of moisture content would alter under those conditions. Further work on these lines will be attempted during the next clear season.

V. Summary and conclusions

(1) It has been shown that dry plant materials exchange moisture with the air layers surrounding them just as the soils do.

(2) The amount of the moisture exchanged is greater than in the soil in the case of materials like dry *jowar* stalk and leaf, while in the case of grains like wheat, paddy, *bajri* and *jowar* the moisture exchanged is less than that by the soil.

(3) The difference between the maximum and minimum moisture content is greatest in materials exposed to open in sun, smaller when exposed to open shaded from sun and least when the specimens are exposed within a Stevenson screen at ground level.

(4) The amplitude of the variation in weight is greater in summer than in winter.

(5) The agricultural bearing of these results has been indicated.

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THE PRACTICAL SIGNIFICANCE OF SOIL SOLUTION STUDIES

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I. Introduction

A few references have been made to the writers direct and sometimes through the Imperial Bureau of Soil Science with regard to the value of displaced solution of soil at its moisture content under normal field conditions. A preliminary survey of the soil solution methods has been made and a few facts about them have been put forth in the following pages.

A 'soil solution' is obtained from a soil of optimum moisture content by the alcohol displacement method of Parker [1921] and other workers as described later on in the paper. The soil solution isolated by this method is the soil water, containing some colloidal and dissolved salts removed unchanged

from the solid mass of soil and forms, to the best of our knowledge, the medium from which the plant draws its nutrients. An examination of the analyses of these solutions enables us to follow the dynamic changes which take place in soils as a result of irrigational, seasonal or cultural variations.

There is a considerable literature on methods of determining the soil solution. One of the first attempts to separate soil solution without recourse to dilution appears to have been made by Schloesing, [1866, 1870], who attempted to displace the soil solution by gravity with water but the method did not work well with soil containing less than 20 per cent water. Itscherekov [1907] improved on Schloesing's procedure by substituting alcohol for water as the displacing liquid. Parker [1921] made a study of the alcohol displacement method and in comparing ethyl alcohol with other liquids such as acetone, methyl alcohol and water, found that ethyl alcohol was the most satisfactory displacing agent. The writers have found out that methylated or rectified spirit yields equally satisfactory results. The method evidently gives the true soil solution, which is at least twenty times as concentrated as the 1 : 5 water extract, though about ten times as much soil is needed compared with the soil used in an ordinary water extract. The greatest advantage it has over water extracts is that it gives a more correct measure of the material in solution. It being concentrated takes least time for evaporation in all micro-determinations used in the investigations.

Burd and Martin [1923] have carried out tests with the gravity displacement method using water instead of alcohol and, in addition, a positive air pressure up to 100 lbs. per sq. inch, thereby hastening the displacement. Their soils seem to be of simpler types and therefore the displaced solutions obtained by them do not exhibit any wider differences in comparison to water extracts of the corresponding soils. They have, however, concluded that the displaced solutions of the soils eliminate some of the more important objections which have been raised to water extraction of the ordinary type. They have stated that the displacement method has much to recommend it in the study of fundamental investigations of soil chemistry in which soluble constituents are concerned.

Burgess [1922], testing the Lipman's method, isolated the soil solution by direct pressure using soil containers capable of withstanding 100,000 lbs. to the sq. inch and compared the extracted solution with 1 : 5 water extracts. The values for the soil bases and other fertility constituents obtained by him (whether expressed on air-dry or oven-dry soil basis) from 1 : 5 extracts are higher than those found in the soil solution in any individual soil.

Data presented in the following pages will show that the discrepancies between the soil solution and water extracts become still more apparent when soils of different kinds are examined. The value of soil solution methods becomes much more reliable when soils of arid regions are examined.

Eaton and Sokoloff [1935] have shown that the proportional and absolute amounts of sodium present in aqueous extracts of soils are higher than those

in displaced soil solution. The proportion of calcium is lower in extracts than displaced solutions.

The results obtained by the writers are shown in the following pages.

II. Research carried out

The principal object of the investigation has been to examine critically the value of soil solution methods and their application to various soil conditions and plant growth in general. Attempt has been made to employ these methods in the study of base-exchange reactions and subsequently in the investigations into the nature of alkali and saline soils.

The comparative value of the examination of soil solution and of water extracts with different soil-water ratios has been studied particularly in case of natural soils rich in soluble bases and also in case of artificially salted soils.

III. Laboratory methods

(*a*) *General considerations*

If water is placed on top and allowed to percolate through a mass of moist soil in a loose state of aggregation, such as that in which it exists in the field under conditions normal to plant growth, successive portions of the liquid obtained will be decreasingly concentrated until a low and comparatively uniform level is reached. None of these portions can properly be assumed to represent the soil solution and the concentration of the entire solution so obtained will doubtless approximate that of a water extract obtained with similar portions of water and soil.

On the other hand if a similar mass of soil is pressed tightly in a tube container and treated with alcohol or any other displacing liquid the successive portions of solution have equal concentrations until the displacing agent begins to appear. These portions, before getting contaminated or diluted, represent true soil solution.

(*b*) *Method of obtaining soil solution*

The method has been described by Parker [1921, 1927], Flint [1927], Mackness [1932] and others, but as it is not widely practised in India and some other countries, a brief description of the writers' technique is given below :—

A bakelite tube or an ordinary glass percolator $2\frac{1}{2}$ inches diameter is closed by muslin tied over the lower end, and moist soil, about two kilos, is then charged into the tube in small quantities at a time, each small addition being pressed down before the next is added. The tube is made to stand in a rack on a funnel containing filter paper and alcohol (methylated or rectified) poured on to the top of the soil. In a few hours drops of soil solution appear, and are collected in a trap flask attached to the funnel. It is remarkable that the solution is seldom at all muddy, in fact the filter paper is almost unnecessary,

and is preferably omitted in most cases. If it is desired to reduce the amount of alcohol required, the displacement may be started with 200 or 300 c.c. of alcohol and after this has penetrated the soil, water may be added to complete the displacement.

It may be emphasised that the soil solution thus obtained is no way an alcoholic extract, neither does it contain any trace of alcohol when the operation is correctly carried out. If the tubes are allowed to stand too long, then the alcohol begins to come through, and can at once be detected by the characteristic appearance which due to defraction differences accompanies the mixing of an alcoholic drop and water. About 50 per cent of the soil solution is displaceable by this method and the successive portions of the liquid obtained give the same freezing point depression [Parker, 1921], and exhibit a constant composition in successive increments.

The method can be used on all soil classes and at a wide range of moisture contents. It has several distinct advantages over other pressure methods which have been used by other workers. One of the greatest advantages is its simplicity and the fact that it does not require any special apparatus.

Relation between moisture and results of analyses.—The direct results of analyses are expressed in parts of nutrients and other bases per million parts of the solution and this represents the concentration of bases and other nutrients at the time of displacement. Finally, however, all the results are expressed on oven-dry soil basis as parts per million or per hundred. Parker and others have shown that at ordinary moisture contents the concentration of the soil solution is inversely proportional to the moisture content of the soil.

(c) *Methods of analyses*

Methods adopted, except in case of sodium, are those generally in use in the Agricultural Chemistry Department of the Imperial College of Science and Technology, London, for work of this kind, and have been tested over a number of years. An easy and short method for the determination of sodium in soils has been successfully worked out [Mulwani and Pollard, 1937]. Accuracy of each method was tested [Mulwani, 1936] with synthetic soil solutions made prior to the research.

Preparation of solution for the estimation of manganese, calcium, magnesium, etc.—Fifty c.c. of soil solution or water extract are evaporated to dryness in a silica dish with a few c.c. of A. R. hyrodchloric acid. The residue is then ignited thoroughly but not too strongly to burn organic matter completely. Five c.c. of A. R. nitric acid and one drop of hydrochloric acid are added and the whole evaporated again on a steam-bath. It is then digested on the steam-bath with 50 c.c. of water, acidified with a few drops of nitric acid, for fifteen minutes or until the flakes of calcium sulphate dissolve. The digested material is filtered through a fitler No : 40 Whatman paper into a 100-c.c. measuring flask (*A*) and made up to volume.

Manganese.—Five c.c. of test solution from flask (*A*) are pipetted in a 60-c.c. beaker and treated with one c.c. of phosphoric acid and a few crystals of potassium periodate and heated to boiling. After allowing it to stand for five minutes it is heated again, stirring all the time to avoid bumping, and made to 10 c.c. The colour developed in presence of manganese is quickly compared with standard.

Preparation of standard.—Direct use of standard potassium permanganate solution in some cases is unsatisfactory as shade of colour is slightly different from that obtained with test solution. Therefore 10 c.c. of $N/20$ potassium permanganate are acidified with sulphuric acid and reduced with oxalic solution and re-oxidised with phosphoric acid and periodate and finally made to 1,000 c.c. The resulting standard is $N/2{,}000$. ($N/10$ $KMnO_4$ contains 1·10 grm. Mn per 1,000 c.c.). The best part of range is between 1-2 c.c. of $N/2{,}000$ potassium permanganate ; with 3 c.c. the colour is difficult to match.

The comparisons are made in exactly similar specimen tubes etched with a mark at a volume of 10 c.c. and standing on a white tile. In one is placed the test solution diluted to 10 c.c., into the other the standard is run from a graduated pipette until on looking down the tubes the tints are seen to be the same. The final comparison is made with the standard diluted to about 10 c.c. so that equal amounts of manganese will be contained in equal volumes of solution. Following recoveries have been made by this method :—

Quantities of Mn taken	Quantities of Mn recovered
(Mg.)	(Mg.)
0·02	0·020
0·02	0·018
0·02	0·018
0·02	0·022
0·05	0·052
0·05	0·050
0·05	0·050
0·05	0·050
0·10	0·104
0·10	0·104
0·10	0·108
0·10	0·100
0·15	0·156
0·15	0·160
0·15	0·160
0·15	0·158

The results indicate the accuracy of the method in presence of very small amounts of manganese. Colour intensity may alternatively be marked in a Hellige colorimeter.

Calcium.—The presence of manganese exceeding 100 p.p.m. interferes with the determination of calcium. Removal is effected by adding 3 grms. of sodium acetate, a few drops of pure bromine, boiling and filtering.

Fifty c.c. of test solution (A) are taken and after treating with 3 drops of concentrated acetic acid it is diluted to 150 c.c. After heating it to boiling 10 c.c. of saturated ammonium oxalate (this precipitates up to 70 mg. Ca) solution are slowly added with stirring. After heating again for ten minutes it is allowed to stand for four hours. The precipitate is filtered through No. 40 Whatman paper and washed well with hot water, the first two washings being collected with the filtrate for estimation of magnesium. The precipitate is rinsed off with cold water and the paper washed through three times with warm dilute sulphuric acid (5 c.c. concentrated acid plus 100 c.c. water). Further 10 c.c. of 1 : 1 sulphuric acid are added and the whole diluted to 150 c.c. After heating nearly to boiling it is titrated with $N/20$ potassium permanganate (1 c.c. $N/20$ $KMnO_4$=1·002 mg. of Ca). Accuracy of the method is shown below :—

Quantitites of Ca taken	Quantities of Ca recovered
(Mg.)	(Mg.)
1·0	0·96
1·0	0·96
2·0	1·90
2·0	1·94
3·0	2·86
3·0	2·98
4·0	4·08
4·0	4·10

Magnesium [Treadwell and Hall, 1915].—The filtrate and washings are boiled down in a 250-c.c. beaker to a volume of about 50 c.c. and 2 c.c. of 10 per cent diammonium hydrogen phosphate solution are added to the hot liquid and 20 c.c. of 10 per cent ammonia stirred in, rubbing when solution has cooled with a rubber-tipped rod, until the precipitate appears. The beaker with the precipitate is allowed to stand, covered to prevent undue loss of ammonia, in the cold for fourteen hours and then filtered through a No. 42 (or 40) paper, washing twice on the paper with one per cent ammonia. The filtrate and washings could be set aside for sulphate determinations. The precipitate is further washed four times on the paper with 30 per cent alcohol (400 c.c. of rectified spirit made up to one litre) rejecting the washings. The filter paper with the washed precipitate is replaced in the beaker with water and left on the hot plate at 60°C. for fifteen minutes to ensure the removal of the ammonia. After cooling an excess of $N/10$ hydrochloric acid is run into the beaker from a micro-burette, usually 5 c.c. suffice ; 30 c.c. of hot water are poured on and this is followed by three drops of a solution of cochineal (1 part crushed beetles digested with 10 parts of 25 per cent alcohol and filtered). After five minutes the liquid is titrated with $N/10$ caustic soda yellow to purple. A blank is carried out, using a piece of the filter paper for each series of estimations.

(N/10 NaOH × 1·21=mg. Mg)

The method is tested :—

Quantities of Mg taken	Quantities recovered
(mg.)	(mg.)
1.0	1.08
1·0	1.02
2.0	2.06
2·0	2.06
4.0	3.86
4·0	3.91

Iron.—Total iron is determined by the thioglycollic acid method as suggested by Lyons [1927]. The solution is first tested qualitatively. From the intensity of the colour obtained the approximate concentration may be assessed. The dilution is then adjusted to about 1 : 500,000. At this dilution the colours obtained are very easy to match. The solution prepared for testing is then transferred to a test-tube marked at 5 c.c. volume. To this is now added one drop of thioglycollic acid and 0·5 c.c. of concentrated aqueous ammonia. The colour produced is then compared with standards of known concentration by means of a Hellige wedge colorimeter.

Quantities of Fe taken	Quantities of Fe recovered
(mg.)	(mg.)
0.1	0.110
0·1	0.110
0·1	0.098
0.2	0.200
0·2	0.220
0·2	0.190
0.5	0.520
0·5	0.500
0·5	0.490

Aluminium.—Aluminium (1·0-20 p.p.m.) is determined directly with a colorimeter, if the solution is clear, by aluminon method [1936]. Quantities between 0·02 and 1·0 parts per million are best measured by comparison with standard in flat-bottom specimen tubes, using three drops of reagent for 5 c.c. of test solution.

The test solution after treatment with the reagent is made up to a definite volume, say 5 c.c., in a test tube. It is then well agitated, heated for five minutes at 100°C. in an evenly heated water-bath and allowed to cool slowly to room temperature.

However, if the test solution is rich in organic matter and calcium sulphate, a simple pre-treatment of the solution is made. Twenty c.c. of the solution are taken in a small silica basin, dried and ignited very gently. If manganese be present the ash is treated with five drops of hydrogen peroxide,

a few c.c. of water, and 2 c.c. of concentrated nitric acid and dried again, and further heated at 105° C. for twenty minutes or at 165° C. for five minutes. Extraction is made with one c.c. of dilute nitric acid (1 : 50). If calcium sulphate is seen at the bottom, it is removed by filtration or centrifuging.

A Hellige wedge colorimeter is used in most cases.

Iron, if present in great excess, interferes in the determination. The solution containing large excess of iron is treated for about five seconds with hydrogen sulphide before putting in the aluminon reagent. Iron, in this manner, is made absolutely inactive, and the aluminium recation is in no way influenced by hydrogen sulphide.

Preparation of aluminon reagent

Aluminium aurin tricarboxylate	0.75 grm.
Ammonium acetate	200.00 grm.
Gum acacia	15.00 grm.
Conc. HCl A. R.	189.00 c.c.

The components are dissolved separately, the gum acacia being filtered through filter paper. the whole being mixed and diluted to 1,500 c.c.

Standard aluminium solution.—1·3662 grm. of $Al_2(SO_4)_3$. ($18H_2O$, A. R.) crystals are dissolved in a few c.c. of water with 2 c.c. of concentrated hydrochloric acid (A. R.). The volume is made to 500 c.c. This gives 221·2 p.p.m. aluminium. The solution is further diluted twenty-five times to get 8·85 p.p.m. aluminium.

Chenery [1936] has found that free aluminium cannot be detected in normal soil solutions of *p*H values between 6·7 and 7·5 ; within a certain range of *p*H the lower the *p*H the higher the aluminium content ; the concentration of other ions had a marked effect on the aluminium content at any given reaction. Accuracy of the method has been tested (4 replications) :—

Al taken	Al recovered
(mg.)	(mg.)
0.010	0.010
	0.009
	0.009
	0.010
0.050	0.045
	0.048
	0.054
	0.050
0.100	0.100
	0.095
	0.100
	0.110
0.200	0.220
	0.200
	0.180
	0.180

Alkalinity (*or* Na_2CO_3).—This is estimated by evaporating a certain volume of soil solution to dryness and extracting the residual with a few c.c. of warm water. The titration is made with $N/100$ hydrocholric acid using phenolphthalein as indicator.

1 c.c. $N/100$ HCl=1·08 mg. Na_2CO_3

Total carbonate in soil.—This is determined by Collins' Calcimeter [1906].

Nitrogen.—This exists in three main forms in the soil and its solution ; as ammonia, as nitrate, and as organic nitrogen. For all the nitrogen determinations the micro-Kjeldahl still of Pregl [1937] is used.

Ammonia.—In this case the solution (about 5 c.c.) is distilled in the ordinary way with 10 c.c. of a 10 per cent magnesia suspension into $N/100$ acid. When there was trouble due to frothing in the distillation with magnesia suspension, it was replaced with 3 c.c. of 40 per cent magnesium sulphate solution plus one c.c. of caustic soda 30 per cent solution with 5 per cent sodium thiosulphate. In this way satisfactory results were obtained.

Nitrate.—In actual practice ammonia and nitrate have been determined together and the amount of ammonia found taken off gives the net value for the nitrate present in the sample.

The nitrate is, in the first instance, reduced to ammonia by the iron reduction method. 0·2 grm. of reduced iron Kahlbaum is added to the solution and 2 c.c. of sulphuric acid (1 : 1) are then carefully pipetted in to rinse down all the iron particles adhering to the neck of micro-Kjeldahl flask. The flask is shaken and stood for five minutes. It is then slightly warmed till the digestion is complete and the solution quite clear. The distillation is carried out as above.

Organic nitrogen.—This form of nitrogen as well has been obtained by differnce between total nitrogen and ammonia plus nitrate. In estimating total nitrogen the procedure is similar to that mentioned above up to digestion with reduced iron. Thereafter the material is treated with one drop of sodium selenite or selenium oxychloride and 2 c.c. of concentrated sulphuric acid. The digestion is carried out carefully to avoid bumping. The flask is kept steady by means of a lead ring round its neck. The distillation is carried out with 16-18 c.c. of 30 per cent caustic soda mixed solution into $N/100$ hydrochloric acid. The accuracy of the methods is tested with following results :—

1. Ammonia (*N*) (*A. R. ammonium sulphate solution used*)

Nitrogen taken 0·211 mg. in duplicate.

Nitrogen recovered.	mg.
(*a*) Distillation with 10 c.c. of 10 per cent MgO suspension . . .	0·205 0·206
(*b*) Distillation with 3 c.c. of 40 per cent $MgSO_4$ solution with a 1 c.c. of 30 per cent NaOH solution	0·204 0·207

2. Nitrate (N) (A. R. potassium nitrate solution used).
Nitrogen taken 0·277 mg. in duplicate.

Nitrogen recovered—	mg.
(*a*) Distillation with 10 c.c. of 10 per cent MgO suspension	0·260
	0·272
(*b*) Distillation with 5 c.c. $MgSO_4$ (40 per cent solution) with 6 c.c. of 30 per cent NaOH solution	0·268
	0·279

3. Total nitrogen in three forms :—
Triplicate quantities taken :

	mg.
N (as ammonium sulphate A. R.)	0·106
N (as potassium nitrate A. R.)	0·139
N (as urea pure)	0·233
Total	0·478

Total nitrogen recovered :

mg.
0·482
0·469
0·475

Phosphoric acid.—Phosphate has been determined by Deniges' colorimetric method, using the Hellige colorimeter. The method as recommended by Parker and Fudge [1927] is followed—

Preparation of the solution.—A convenient quantity of soil solution (containing PO_4 from 2 to 14 mg.) is pipetted into a deep porcelain crucible. Two c.c. of dilute nitric acid are added and the solution evaporated on the hot plate at 60°C. The residue is heated very carefully, but sufficiently to render organic matter insoluble. Pre-ignition in an electric oven at 160°-180°C. is preferable when calcium content is high. Risk of explosive ignition of calcium nitrate with organic matter is thus restricted. The material is then taken up in 0·2 c.c. of 5 per cent hydrochloric acid and washed into a measuring flask, adding 0·1 c.c. of molybdic reagent and making up to the mark. If the solution is turbid it is cleared by centrifuging at 3,000 r.p.m. This is then treated with one drop of stannous chloride reagent and the blue colour developed compared with standards similarly treated with molybdic and stannous chloride reagents.

Calibration curves may be prepared from different standards which will afford an easy calculation of result.

Ammonium molybdate reagent.—One hundred c.c. of 10 per cent ammonium molybdate solution are mixed with 300 c.c. of a 50 per cent (by volume) sulphuric acid. The acid must be free from arsenic and the reagent kept in the dark or stored in a brown bottle.

Stannous chloride reagent.—To 0·1 grm. of powdered tin is added one drop of 4 per cent solution of copper sulphate and 2·0 c.c. of concentrated hydrochloric acid free from arsenic. The material is warmed to hasten the reaction and the reagent diluted to 10 c.c. This reagent must be prepared fresh every day.

Standard phosphate solution.—0·1433 grm. of potassium dihydrogen phosphate is dissolved in distilled water and made to 1,000 c.c. in a measuring flask. This is protected with a thin layer of toluene. The solution contains 100 p.p.m. of phosphate. Dilutions are made according to the standard desired.

Potassium.—The silver cobalti-nitrite method for the micro-determination of potassium (0·02 to 0·8 mg.) in soil solutions as worked out by Ismail and Harwood [1937] has been adopted by this department.

The method described has been tested and found to give accurate results for amounts of potassium between 0·02 mg. and 0·8 mg.

In the case of saline soils, which are exceedingly rich in potassium, very small volumes, 0·1 c.c. to 1·0 c.c., are taken for the determination or else the amount of potassium exceeds the range (0·02—0·8 grm.) of determination. It has been found that the chlorine content of the solution, which is easier to know, gives a rough index of the potassium content of the solution. On knowing the chlorine content one could decide the volume of the solution to be taken for the determination of potassium to be within the range of the determination.

From general experience, the following table has been prepared to serve in judging the volume of solution to be employed in the determination :—

Cl p.p.m.	Vol. of s.s. in c.c.
10-25	5
25-100	2
100-250	1
250-500	0·5
500-5000	0·2
5000-10000	0·1

However, these should be considered as very approximate figures, as it is observed that salt-affected unleached soils are exceedingly high in potash content, while leached soils are very much poorer in the same.

Data to show the accuracy of the method of potassium determination
(*K as KNO_3 A. R.*)

Quantities of K taken in duplicate (mg.)	Quantities of K recovered (mg.)
0·02	0·022
	0·020
0·05	0·054
	0·049
0·10	0·092
	0·120
0·20	0·204
	0·202
0·40	0·390
	0·398
0·80	0·756
	0·786

K as (KNO_3 A. R.) in presence of 5 c.c. of Slough (England) soil solution.

Quantities taken of K in duplicate	Quantities* of K recovered
(mg.)	(mg.)
0·05	0·044
	0·048
0·10	0·102
	0·096
0·20	0·188
	0·196

Hydrogen-ion concentration (p*H*).—Quinhydrone electrometric method has been followed in the case of Devon soils, while colorimetric method has been adopted in the case of alluvial calcareous soils from Sind.

(1) The quinhydrone electrode portable apparatus is described and designed by Brown and Broom [1929].

Standards were :—

0·2 N sodium acetate

0·2 N acetic acid

9 c.c. acid plus 1 c.c. acetate gave 3·72 *p*H

1 c.c. acid plus 9 c.c. acetate gave 5·57 *p*H

The order of accuracy of the method was 0·02 *p*H.

(2) For the determination of *p*H values of soil solutions colorimetrically two apparatuses have been used :—

(*a*) The B. D. H. capillator, and

(*b*) The Lovibond Comparator.

Soil moisture.—Moisture is determined by heating 5 to 10 grm. of soil in a well ventilated electric or air oven at 105°C. for twenty-four hours.

Sodium was determined by the colorimetric method mentioned in a previous publication [Mulwani and Pollard, 1937]. This procedure is further simplified in case of saline soils as the solutions of these soils are absolutely free from acidity and contain little phosphate or organic matter to interfere in the precipitation of sodium uranyl zinc acetate. Treatments with alcoholic zinc acetate-hydroxide as given by McCance and Ship [1931] has been found unnecessary in case of saline soils.

*These quantities are net after deducting the quantity of K in the soil solution.

A comparison of original McCance and Ship's detailed and the authors' simplified methods yielded following results :—

Mg. of sodium taken	Mg. of sodium recovered			
	(i) McCance detailed method	Mean value	(*ii*) Simplified method	Mean value
0·0393	0·038 (2)		0·039 (6)	
	0·039 (8)		0·038 (9)	
	0·038 (8)		0·039 (8)	
	0·039 (6)	0·039 (1)	0·039 (3)	0·039 (4)
0·0786	0·077 (7)		0·078 (2)	
	0·078 (4)		0·078 (2)	
	0·078 (1)		0·079 (0)	
	0·079 (0)	0·078 (3)	0·078 (6)	0·078 (5)
0·1180	0·117 (1)		0·117 (6)	
	. .		0·118 (8)	
	0·117 (7)		0·118 (6)	
	0·118 (0)	0·117 (6)	0·117 (8)	0·118 (2)
0·1570	0·15 (7)		0·15 (8)	
	0·15 (8)		0·15 (6)	
	0·15 (7)		0·15 (8)	
	0·15 (8)	0·15 (8)	0·16 (0)	0·15 (8)
0·2360	0·23 (6)		0·23 (4)	
	0·23 (4)		0·23 (8)	
	0·23 (5)		0·23 (8)	
	0·23 (5)	0·23 (5)	0·23 (8)	0·23 (7)

Thus it is seen that the simplified method is quite perfect.

IV. Soils used in the investigation

Soils from Devon (England) and Sind (India) were examined through the consideration of their displaced solutions and corresponding water extracts. A brief description of each soil is given below :—

(*a*) *Devon*

The soil was originally received from Greenwell Farm and was under grass. High ammonia content (Table VII) was perhaps due to long storage. Mechanical composition of the soil is given :—

	per cent
Course sand	13·42
Fine sand	29·40
Silt	22·55
Clay	19·75
CO_3	<0·20
Organic matter	9·30
Loss by solution	1·45

Composition of the soil solution (Table VII) shows that excepting potash, which is low, the soil is fairly rich in other constituents. It is acidic in reactions.

(*b*) *Sind*

The soils, which are both made and maintained by the huge River Indus, are fertile. They are deep, calcareous alluviums, mostly loamy, with a low water-holding capacity and a very low humus content. As a result of successive deposition and erosion by the Indus, the proportions of sand and clay vary considerably within even the smallest areas. The soil profile is undefined and structureless. A striking feature of these soils is their lack of uniformity over any distance. A number of pits, which have been dug to a depth of 5 to 6 feet in a series of plots show distinct layers of soils deposited one over the other, the order of deposition being often different in different pits. In one of the pits the thickness of different layers and their arrangement was as follows [Tamhane and Daji, 1929] :—

Layer	Texture	Composition (per cent)	
		Silt+clay	Fine sand
First layer (0—7 in.)	Clay loam	46·90	53·10
Second layer (7—19 in.)	Loam	30·41	69·59
Third layer (19—25 in.)	Clay loam	50·77	49·23
Fourth layer (25—46 in.)	Sandy loam	14·38	85·62
Fifth layer (46—72 in.)	Stiff clayey	79·70	20·30

The thickness and the nature of the layers, however, varies in different pits. Besides these differences of texture the soluble salt content (comprising mostly NaCl and Na_2SO_4) of each layer varies very markedly [Tamhane and Mulwani, 1934].

It is obvious that the results obtained at one place cannot be applied to another place. This does not, however, mean that there is nothing of general importance. There are many things which are, in spite of the heterogenity of the soil, found to be common in movement and storage of water and bases in these soils. The soils in general are slightly alkaline in reaction. Iron, aluminium and manganese, therefore, do not appear in the solution of these soils. Phosphate also remains mostly in insoluble form.

The rainfall is scanty, the average being 3 inches per annum, which is mostly received during the summer months in light showers. Under these soil and climatic conditions, the agriculture therefore depends entirely upon irrigation throughout the country.

V. Experimental

Attempt has been made to study the possibility of applying soil solution methods to investigations of causes of soil exhaustion, deterioration and subsequently find out methods of soil amelioration and general improvement to permit normal plant growth.

The work for the sake of simplicity and convenience has been divided into the following main sections :—

(*a*) Co-relation between soil productivity and its soluble constituents. Soil conditions, under normal and poorer growths of ordinary farm crops, like wheat (*Triticum sativum*), *Jowar* (*Sorghum Vulgare*) and cotton (*Gossypium neglectum*), were examined through considerations of soil solutions, water and hydrochloric acid-extracts.

(*b*) Comparison of displaced soil solutions and water extracts in the saline and alkaline soils, and

(*c*) base-exchange reactions in soils.

Each section is dealt with separately :—

(*a*) *Soil solution* vs. *soil productivity*

Soils of known productivity in the field which were free from injurious salts were taken up and examined through considerations of soil solutions, water extracts and chemical analyses respectively. The results of the analyses have been put up in Tables I (*a*) and I (*b*).

TABLE I (*a*)

Composition of soil solution and water extract from soils of known productivity

Soil	Displaced soil solution										1 : 5 water extracts							
	(lbs) Yield per plot (1/16 acre)		1 Total soluble matter (per cent)	2 Ca (per cent)	3 Mg (per cent)	4 Na (per cent)	5 K (per cent)	NO_3 (per cent) mg.	PO_4 p.p.m.	*p*H	1 Total soluble matter (per (cent)	2 Ca (per cent)	3 Mg (per cent)	4 Na (per cent)	5 K (per cent)	NO_3 (per cent)	PO_4 p.p.m.	*p*H
	Grain	Total dry wt.																
								(i) Wheat										
A	21	71	0·022	0·002	0·003	0·003	0·001	T	T	8·2	0·08	0·006	0·002	0·002	0·002	T	3·0	7·4
B	38	100	0·054	0·006	0·004	0·006	0·002	0·10	T	7·8	0·120	0·008	0·003	0·003	0·002	0·10	3·6	7·6
C	47	112	0·061	0·006	0·004	0·005	0·002	0·24	0·1	7·6	0·092	0·014	0·004	0·005	0·003	0·2	3·8	7·3
D	57	135	0·104	0·008	0·005	0·004	0·002	0·55	0·2	7·6	0·150	0·012	0·004	0·004	0·005	0·7	3·8	7·4
E	73	172	0·118	0·012	0·004	0·003	0·003	0·62	0·2	7·4	0·162	0·022	0·006	0·007	0·004	0·7	4·0	7·3
F	82	210	0·120	0·015	0·003	0·003	0·004	1·10	0·3	7·2	0·150	0·020	0·006	0·008	0·005	1·2	4·0	7·6
								(ii) Jowar										
G	33	516	0·022	0·003	0·003	0·004	0·001	T	T	8·0	0·08	0·006	0·001	0·002	0·004	T	2·0	7·4
H	46	619	0·08	0·008	0·004	0·008	0·002	0·20	0·1	7·9	0·22	0·008	0·006	0·006	0·008	0·2	2·2	7·6
I	64	677	0·16	0·010	0·004	0·005	0·004	0·50	0·2	7·4	0·28	0·022	0·005	0·008	0·012	0·5	3·6	7·6
J	83	816	0·16	0·018	0·003	0·003	0·005	1·50	0·3	7·4	0·20	0·020	0·004	0·006	0·010	1·8	3·2	7·4
								(iii) Cotton										
	Seed cotton																	
K	52		0·20	0·006	0·006	0·012	0·002	0·40	T	8·4	0·40	0·040	0·005	0·02	0·01	0·8	4·4	7·4
L	97		0·21	0·019	0·003	0·004	0·006	1·40	0·4	7·4	0·25	0·022	0·004	0·006	0·01	1·2	3·4	7·6

T = Traces.

(Columns 1-5, figures expressed on oven-dry soil)

All soils are more or less of similar texture.

TABLE I (*b*)

Ca-Na, Ca-Mg and Na-K ratios in displaced soil solutions and corresponding water extracts from soils of known productivity (Table Ia)

	Displaced soil solution			1 : 5 water extract		
	Ca : Na	Ca : Mg	Na : K	Ca : Na	Ca : Mg	Na : K
Soils under wheat						
A	0·66	0·66	3·00	3·00	3·00	1·00
B	1·00	1·50	3·00	2·66	2·66	1·50
C	1·20	1·50	2·50	2·80	3·50	1·66
D	2·00	1·60	2·00	3·00	3·00	0·80
E	4·00	3·0	1·00	3·10	3·66	1·75
F	5·00	5·0	0·75	2·50	3·66	1·60
Soils under jowar						
G	0·75	1·0	4·00	3·00	6·00	0·50
H	1·00	2·0	4·00	1·33	1·33	0·75
I	2·00	2·5	1·25	2·75	4·40	0·66
J	6·00	6·00	0·60	3·33	5·00	0·60
Soils under cotton						
K	0·50	1·00	6·00	2·00	8·00	2·0
L	4·75	6·33	0·66	3·66	5·50	0·6

Table I (*a*) presents values for total soluble matter and *p*H ; soluble plant food ingredients and bases both from soil solution and water extracts are also given. The data is self-explanatory. Definite co-relation between the composition of soil solution and plant performance is established. Water extracts on the other hand fail to give any information about the soil productivity. Taking each determination separately it is observed (*i*) that the increased total soluble matter as represented by the displaced soil solution agrees closely with the corresponding increases in the yield of crops whereas no such agreement is exhibited by the water extract of these soils. Water extracts in general represent larger amounts of soluble matter. (*ii*) Calcium of the soil solution increases with the soil productivity whereas calcium of extracts is somewhat misleading, *e.g.*, soil (K) which is inferior to (L) has yielded higher calcium in extract ; similar discrepancies are shown by the extracts in (E) and (F) soils and also in (I) and (J). (*iii*) Increase of potassium in soil solution corresponds with the increase in the yield of crops

whereas extracts fail to show such regularity. (*iv*) Though the differences between the magnesium contents are not remarkable it is observed that its ratio with calcium (Ca : Mg) in soil solutions as shown in Table I(*b*) is a good indicator of soil fertility. Calcium-magnesium ratio of the soil solution increases with the soil fertility. This is not seen in case of water extracts. (*v*) Sodium of the displaced solution tends to decrease with the richness of the soil. Water extracts show higher sodium content. Sodium values help in forming useful ratios such as calcium-sodium and sodium-potassium in soil solutions, the former increasing with increase in fertility and the latter decreasing. Water extracts are less reliable in this connection. (*vi*) Nitric nitrogen, both in case of soil solutions and extracts, shows higher with higher yields. Water extracts appear to draw out more of nitrate. (*vii*) Soil solution phosphate figures agree with the productivity of the soil, whereas the water extracts fail to show such relationship. On the other hand larger quantities of phosphates are shown by the extracts than what actually are available for the use of plants in the soil. (*viii*) *p*H values of the soil solutions yield very useful information and agree with calcium-sodium ratio. Water extracts on the other hand show great discrepancies about it. With a view to judge the soil solution data as shown in Table 1 (*a*) and compare it with the standard chemical analyses all the twelve soil samples (A-L) were subjected to various fertility constituent determinations, such as total nitrogen, potash, phosphoric acid and lime content. The results of analyses, as shown in Table II, fail to give any useful information with regard to the crop-yielding capacity of the soil.

TABLE II

Chemical analyses of (A-L) soils for total soil-fertility ingredients

Soil	Total nitrogen per cent	K_2O per cent	P_2O_5 per cent	Ca per cent
A	0·06	0·5	0·15	6·92
B	0·05	0·7	0·15	5·89
C	0·05	0·5	0·24	7·14
D	0·04	0·6	0·18	5·08
E	0·06	1·1	0·32	7·06
F	0·06	0·7	0·25	6·24
G	0·05	0·6	0·18	6·22
H	0·06	0·4	0·08	5·88
I	0·05	1·4	0·31	7·20
J	0·06	0·9	0·22	6·02
K	0·06	1·3	0·42	7·18
L	0·06	1·0	0·38	6·82

Total nitrogen was determined by Kjeldahl-Gunning Jodlbaner process.

Even the poorer soils appear to be fairly rich in the main reserved plant food ingredients. This data does not exactly inform us which of the soils lack in available plant food material. The soil solution data seem to rightly apply to the immediate productivity of the soils.

(*b*) *Composition of displaced soil solution and water extracts in the saline and alkaline soils*

It is customary in detecting excessive salinity in saline and alkaline soils of various countries to utilise 1 : 5 water extracts for the purpose and to set out as limits of safety the values as under :—

Total soluble solids not more than 5,000 p.p.m. on dry soil.

NaCl not more than 2,000 p.p.m.

Ca not less than 500 p.p.m. of which not less than 100 p.p.m. occurs as carbonate.

As noted in the introduction to this paper, considerable divergencies are probable between the amounts of soluble matter in soils determined by means of soil extracts and those determined with soil solutions. In order to have more definite idea of these divergencies in case of alkali and saline soils three typical salt-affected soils were examined and the data obtained is shown in Table III.

TABLE III

Composition of displaced soil solution and of water extracts of varying soil-water ratios in (*a*) *alkaline soil,* (*b*) *medium alkaline soil and* (*c*) *saline soil*

	Soil : water ratio	1 Total soluble matter	2 Ca	3 Mg	4 Na	5 K	6 Na_2CO_3	7 PO_4	Ca : Na ratio	Ca : Mg ratio	Na : K ratio	*p*H
(*a*) Alkaline soil	Soil solution at 18 per cent moisture . 100 : 18	25,015	105	120	4,280	318	864	T	0·02	0·87	13·5	9·8
	1 : 1 . .	25,218	220	125	4,018	444	401	0·2	0·05	1·76	9·1	9·1
	1 : 2·5 .	36,714	650	156	3,945	616	45	1·2	0·16	4·17	6·4	8·5
	1 : 5 . .	42,516	2,284	202	3,902	892	*Nil*	2·2	0·58	11·30	4·4	7·6
	1 : 10 .	46,412	2,842	226	3,864	926	*Nil*	4·0	0·73	12·6	4·2	7·6
(*b*) Medium alkaline soil	Soil solution 100 : 15	18,370	124	118	3,892	298	212	0·4	0·03	1·05	13·06	9·2
	1 : 1 . .	25,672	427	124	4,064	388	84	0·4	0·15	3·44	10·5	8·9
	1 : 5 . .	32,544	2,596	216	3,964	578	*Nil*	2·0	0·65	12·02	6·9	7·5
	1 : 10 .	38,484	3,016	248	4,118	784	*Nil*	4·0	0·73	12·16	5·3	7·4
(*c*) Saline soil	Soil solution 100 : 16	13,029	141	133	3,773	275	63	0·2	0·04	1·0	13·7	8·9
	1 : 1 . .	12,760	554	80	3,537	394	*Nil*	0·2	0·16	7·0	9·0	7·8
	1 : 5 . .	21,820	2,164	140	3,537	570	*Nil*	4·0	0·61	15·5	6·2	7·6
	1 : 10 .	31,550	4,068	158	3,520	737	*Nil*	6·0	1·17	25·5	4·6	7·6

(Figures (1 to 7) expressed as parts per million on oven-dry soil)

With the widening of the soil-water ratio there is a marked increase in the apparent values of the soluble calcium, potassium, phosphate and total soluble matter, a less marked increase in magnesium and no change in sodium. The values for base ratios, calcium-sodium and calcium-magnesium, increase and those for sodium-potassium decrease rapidly as the proportion of water used is increased.

A further point of interest is that high alkalinity due to sodium carbonate shown in soil solution analyses disappears in the soil extracts. Presumably at the greater dilution precipitation of calcium and/or magnesium carbonate takes place ; also the high calcium content of the water extract tend to suppress dissociation of the sodium clay and the consequent formation of sodium carbonate. The phosphate of the extracts is correspondingly higher than that of the soil solution.

There seems no continuity between the variations in values obtained with the different soils in water extracts and that appearing in the soil solutions.

The combined experience of other workers in this department and elsewhere points out to the fact that the proportionality between values obtained with the soil solution and those with any particular soil-water ratio differ from soil to soil and in the same soil as a result of different cultural or irrigational treatments.

It seems, therefore, that the safety limits used in practice of water extracts are purely empirical, and their application to different soils is of doubtful value. The divergence between the *p*H and sodium carbonate content of soil solutions and of extracts may also lead to erroneous conclusions. Sodium carbonate and *p*H values of the soil solutions clearly indicate the dynamic aspects of saline and alkaline soils. Soil (*a*) which has shown higher sodium carbonate and *p*H values is evidently a sodium or alkaline soil and has persisted to remain barren even after heavier applications of lime and water in the field trials. Soil (*c*) with lower sodium carbonate and *p*H value is a saline soil and has been fully reclaimed on mere flooding with irrigation water. Soil (*b*) is a medium alkali type and has been reclaimed with great amount of difficulty and is yielding poorer crops.

It is thus observed that it is clearly impossible to get this information from water extracts which do not show any differences with regard to degree of alkalization.

It is, however, suggested that the re-adjustment of base-exchange equilibrium occurring during the preparation of soil-water extracts could easily be compared with that taking place during irrigation and leaching. This matter will more comprehensively be dealt with later on.

Analyses of water extracts prepared with a series of different soil-water ratios may therefore serve to forecast the results of irrigation with varying amounts of water.

(c) *Base-exchange reactions in soils*

The importance of exchangeable bases in soil needs no emphasis. It is well known that a large amount of food material in soils for the use of plants resides in the exchangeable complex, and some of the most fertile soils are those rich in exchangeable bases. The knowledge of the nature and amount of exchangeable bases is of prime importance in all studies of the soil conditions and plant growth.

These reactions are clearly understood in healthy and non-saline soils and several methods have been accurately fixed up for the determination of exchangeable bases. But these methods do not work well in case of saline and alkaline soils. This has also been supported by Hissink [1938]. The main reason has been the practice of determining exchangeable bases in such soils by subtracting the water-soluble bases, as found for example in aqueous extracts, from total bases which results in serious error. It should never be assumed that the water extract results are applicable to ordinary field conditions. It has been clearly shown in Tables I and III and elsewhere that the water extracts do not always give a true picture of the soil conditions and in many cases the analyses are not sufficiently reliable for accurate interpretations. The proportional and absolute amounts of bases in water extracts are quite different from those of the displaced solutions [Burgess, 1922]. This fact has to be remembered at all stages in base exchange studies.

As mentioned before, Eaton and Sokoloff [1935] showed that the proportional and absolute amounts of sodium present in aqueous extracts of their soils were higher than those in displaced soil solutions. While the proportion of calcium is lower in extracts than in displaced solutions. The most satisfactory explanation of this phenomenon given is that a cation-exchange reaction takes place when the water-soil ratio is increased. In this exchange, calcium enters the absorbing complex and sodium is liberated.

However, in the case of saline or alkaline soils containing calcium carbonate, as shown in Table III, the amounts of calcium tends to increase with the dilution. New calcium is liberated into solution on dilution from the soil complex, whereas sodium which is in excess is not much affected.

Such reactions appear to remain depressed under optimum or lower moisture content of the soil as shown by the previous data and as also seen from the following experiment.

A healthy normal soil was taken up and treated with 1·0 per cent sodium chloride and equivalent amounts of sodium sulphate (1·22 per cent) and sodium carbonate (0·91 per cent) to find out the influence of these salts on the soil through considerations of the differences in the displaced soil solutions and corresponding water extracts with 1 : 5 soil-water ratio.

Batches of two kilos of moistened soil were mixed in 1·0 per cent sodium chloride, 1·22 per cent sodium sulphate and 0·91 per cent sodium carbonate respectively and stored in lightly covered basins for a week to ensure that

a condition of base equilibrium was attained. In general practice, soils containing 0·5 per cent sodium chloride or sodium sulphate yield satisfactory crops after heavy irrigations. Those containing 1·0 per cent and upward are definitely harmful. Sodium carbonate is injurious even in very small amounts. The results obtained from the soil solutions and from water extracts with 1 : 5 soil-water ratio are shown in Table IV.

TABLE IV

Base-exchange reactions in soil on application of salts and water

(*Figures expressed as p.p.m. on dry soil ; pH values and Ca : Na ratio*)

Soil		Soil : Water	Total soluble matter	Ca	Mg	Na	K	Ca : Na ratio	Na_2CO_3	pH
A	Original (untreated) .	Displaced soil soln..	1,116	145	32	31	46	4·7	*Nil*	7·3
		1 : 5 extract . .	1,946	248	58	55	94	4·5	*Nil*	7·4
B	Same with 1 per cent NaCl	Displaced soil soln.	10,990	178	40	3,934	59	0·04	T	7·6
		1 : 5 extract . .	14,486	1,582	96	3,640	508	0·43	*Nil*	7·4
C	With 1·22 per cent Na_2SO_4 (equivalent of 1 per cent NaCl) .	Displaced soil soln.	12,880	171	42	3,918	62	0·04	T	7·5
		1 : 5 extract . .	16,265	1,565	102	3,690	550	0·42	*Nil*	7·4
D	With 0·91 per cent Na_2CO_3 (equivalent of 1·0 per cent NaCl) .	Displaced soil soln .	10,010	68	24	3,925	54	0·017	8,992	11·9
		1 : 5 extract . .	14,208	102	60	3,070	486	0·03	6,014	9·2

The data presented under A in Table IV show that the extract brings out comparatively larger total soluble matter and other bases even from untreated healthy soil. These reactions, due to base-exchange phenomenon, are very much accelerated on extraction with sodium chloride and sodium sulphate. Calcium and potassium represented by the extract are about nine times higher than that of soil solution with sodium chloride or sodium sulphate (B and C). The increase in calcium on extraction correspondingly increases calcium-sodium ratio. Na reactions could be examined by substituting ammonium salts instead of sodium salts in the base exchange. Hissinks method is based on these principles of base exchange but applies only to soils which are free from salts.

(D) Solubility of calcium and magnesium, however, remains depressed on treatment with 0·91 per cent sodium carbonate both in displaced soil solution and in extract. This is due to double reaction, *viz.*, usual displacement of calcium and magnesium in first stage and subsequent precipitation of these with the excess of sodium carbontate in second stage. This is confirmed by reduction in sodium carbonate, calcium-sodium ratio and *p*H of water extracts.

This double reaction of sodium carbonate was critically examined through considerations of displaced soil solutions and water extracts of the same healthy soil on treatment with smaller amounts of sodium carbonate. The soil was

treated with 0·01, 0·10, 0·2 and 0·3 per cent sodium carbonate respectively and kept moist exactly as done in previous case. Results of analyses as given in table V clearly show that sodium carbonate added to the soil is more or less completely recovered in all cases of displaced soil solutions. Water extracts fail to give fully the amounts of all the sodium carbonate added to the soil. It is evident that sodium carbonate up to certain limit is precipitated by the displaced lime on extraction. Calcium displaced in sodium carbonate treatment up to 0·1 per cent is more than sufficient to precipitate all this amount of sodium carbonate. Consequently the water extract with 0·1 per cent sodium carbonate treatment neither shows any presence of sodium carbonate nor any rise in *p*H. Excess of sodium carbonate, however, depresses the solubility of calcium or partly utilises the displaced lime in its partial precipitation. This double reaction is therefore responsible for the reduction in recovery of sodium carbonate in water extracts.

Table V

Effects of different concentrations of Na_2CO_3 on normal soil

(*Figures expressed as p.p.m on dry soil*)

Treatment	Soil : Water	Total soluble matter	Ca	Mg	Na	K	Ca : Na ratio	Na_2CO_3	*p*H
(*i*) Original healthy soil .	Displaced Soil Soln.	1,116	145	32	31	46	4·7	*Nil*	7·3
	1 : 5 extract .	1,946	248	58	55	94	4·5	*Nil*	7·4
(*ii*) Same with 0·01 per cent Na_2CO_3 . . (*i.e.*, 100 p.p.m.)	Displaced Soil Soln.	1,186	130	30	79	50	1·7	89	8·2
	1 : 5 extract . .	1,224	890	74	83	114	10·7	*Nil*	7·3
(*iii*) With 0·1 per cent Na_2CO_3 . . . (*i.e.*, 1,000 p.p.m.)	Displaced Soil Soln.	2,054	114	30	482	50	0·24	951	9·4
	1 : 5 extract . .	2,482	1,497	98	448	290	3·34	*Nil*	7·7
(*iv*) With 0·2 per cent Na_2CO_3 . . . (*i.e.*, 2,000 p.p.m.)	Displaced Soil Soln.	3,078	110	30	914	52	0·12	1,900	10·1
	1 : 5 extract . .	4,418	224	70	865	310	0·26	804	8·8
(*v*) With 0·3 per cent Na_2CO_3 . . . (*i.e.*, 3,000 p.p.m.)	Displaced Soil Soln.	4,024	88	28	1,227	52	0·07	2,832	10·9
	1 : 5 extract . .	5,892	108	66	1,025	396	0·11	1,704	9·2

It is interesting to note that the displaced soil solution presents true condition of the degree of salinization or alkalization, calcium-sodium ratio and *p*H values which will not be possible with water extracts.

These base-exchange reactions suggested to know exactly the Ca status in soils in absence or presence of salts. An attempt has therefore been made to find out exchangeable calcium in saline and non-saline soil through considerations of soluble calcium both in soil solutions and water extracts. Three soils :—one normal, second artificially salted and the third natural alkaline

soil were taken up for the study and the data obtained were given below in Table VI.

TABLE VI

Comparison of soil solutions and water extracts in the determination of exchangeable Ca in

(*a*) *normal healthy soil* (*Table IV*).

(*b*) *artificially salted* (*1 per cent Nacl*) *soil* (*Table IV*).

(*c*) *Natural alkaline soil* (*Table III*).

(*i to iii expressed as p.p.m. ; iv as m.e. per 100 grm. of soil.*)

		(*i*) Soluble Ca	(*ii*) Total (Sol+Ex)	(*ii-i*) (*iii*) Exch Ca	(*iv*) Exch Ca M. E.
Soil (*a*)	Displaced soil soln. . .	145	1,810	1,665	4·16
	1 : 5 Extract . . .	248	..	1,582	3·95
Soil (*b*)	Displaced soil soln. . .	178	1,810	1,632	4·08
	1 : 5 Extract . . .	1,582	..	228	0·57
Soil (*c*)	Displaced soil soln. . .	105	3,025	2,940	4·82
	1 : 5 Extract . . .	2,248	..	741	0·18

The data amply manifests that the reserve calcium is liberated from the soil and comes in solution due to base exchange on treatment with a sodium salt. This reaction is very much enhanced in presence of larger quantities of water. In 1: 5 extract of the artificially salted soil (*b*) we observe that the exchangeable calcium is reduced from 4·08 to 0·57 m.e. per 100 grms. of soil. This reduction is evidently due to the liberation of absorbed calcium in the soil and going in solution due to the presence of salt and water. Deterioration of some of the healthy soils on salt intrusion occurs mainly due to this phenomenon. Calcium is leached out from the soil on flooding or irrigation resulting into sodium soils. Unless large reserves of finely and well distributed calcium carbonate are present the soil becomes practically unfit for cultivation and plant growth.

Addition of soluble salts of calcium like calcium sulphate or calcium chloride may at larger expenses recoup the lost calcium and help in reclamation of the deteriorated soils. Prevention is, therefore, always better than cure. The essential feature in the management of such irrigated lands are firstly the exclusion of sodium salts and secondly judicious use of irrigation water.

In the final series it was sought to find out the influence of pure sodium chloride in different amounts on a healthy soil from Devon (England) through the consideration of the differences in the displaced soil solutions from the original soil and that from the salted samples. Figures of analyses obtained are shown below in Table VII.

TABLE VII

Davon soil

(p.p.m. on oven-dry soil and pH values)

Treatment	Ca	Mg	Na	K	Fe	Al	Mn	PO_4	*p*H	NH_3
A—Original soil (untreated)	36·1	1·7	30·4	6·8	*Nil*	1·7	6·0	1·96	5·9	29
B—With 0·5 per cent NaCl	340·6	258	1,013	36·37	*Nil*	14·5	76·5	*Nil*	5·52	84
C—With 1·0 per cent NaCl	398·0	344	2,085	39·4	*Nil*	52·4	99·3	*Nil*	5·15	93
D—With 1·5 per cent NaCl	512·6	348	3,192	40·8	*Nil*	52·4	128·0	*Nil*	4·90	95

Same expressed as equivalents p.p.m.

	Ca	Mg	Na	K
A—Original soil	1·8	0·14	1·32	0·174
B—With 0·5 per cent NaCl . . .	17·0	21·30	44·0	0·938
C—With 1·0 per cent NaCl . . .	20·0	28·40	90·6	1·010
D—With 1·5 per cent NaCl . . .	25·6	28·76	139·0	1·043

It will be seen in general that the bases are brought into solution by sodium chloride ; *p*H values that are lowered down are due to, in the opinion of the writers, the following reaction :

H-complex of the soil + NaCl → HCl + Na-complex.

Increase in the dose of sodium chloride brings out an increased amount of calcium though it is not proportionate. In the case of potassium and magnesium the reaction is practically complete with one per cent sodium chloride.

Examination of the sodium values shows that in the three salted soils the sodium concentration of the soil solution is increasing regularly with the amount of sodium chloride added. Soil being acidic and unsaturated appears to adsorb sodium of sodium chloride. Even with the heavier treatments sodium still continues to disappear from solution since each increase of sodium chloride (0·5 per cent) represents 86 equivalents of sodium per million parts of dry soil, whereas the correspondent treatments in soil solution concentrations are equivalent to 47 equivalent parts per million of dry soil.

Exchange reactions on magnesium and potassium appear to have ceased with the 1·0 per cent application. With 1·5 per cent salt, displacement of calcium from the clay complex and possibly to some extent from calcium carbonate present in the soil still continues together with that of aluminium and manganese. A more deep seated reaction than that of ordinary base exchange is thus indicated.

*p*H changes are such as would be anticipated as the result of neutral salt additions to a normal soil of low calcium carbonate content.

The disappearance of phosphate from the soil solution of salted soils is noteworthy, as also is the increased proportions of Al appearing in solution. It seems possible that aluminium liberated from the soil complex by the neutral salt action is causing the removal of phosphate as aluminium phosphate. As will be seen later, small amounts of phosphate in the soil solution are characteristic of Sind saline soils examined, but in this case there is a larger proportion of (approximately 10 per cent) calcium carbonate present. The Devon soil used in these tests has less than 0·2 per cent calcium carbonate. In order to facilitate compa rison with previous soils it was desirable to ascertain whether calcium carbonate affected the action of sodium chloride in decreasing the solubility of phosphate a further sample of the soil was mixed with 10 per cent of calcium carbonate and 1·0 per cent sodium chloride and the soil solution examimined after several days. Values obtained were :—

	Fe	Al	Mn	PO_4	*p*H
Untreated soil . . .	*Nil*	1·8	8·0	2·1	5·2
Soil with 10 per cent $CaCO_3$ and 1 per cent NaCl .	*Nil*	*Nil*	*Nil*	*Nil*	6·8

In the presence of calcium carbonate, therefore, salt suppresses the solubility of phosphate and also that of aluminium and manganese. This condition is also similar to that of Sind saline soils. Further, in view of these results it appears unlikely that aluminium is concerned in the reduced phosphate solubility under saline conditions.

VI. Discussions

The main object of the research was to make a detailed inquiry into the status of soil solution and to study the application soil solution methods to investigation of causes of soil productivity, exhaustion or deterioration. Little or no information is available as to the composition of soil solutions from saline and arid region areas, and it appeared likely that the examination of soil solutions would yield information of value in this respect. The validity of this assumption is examined. For reasons already set out, the divergence, between the composition of soil solution and corresponding water extracts, is a matter of some importance if the values of soils are assumed to represent the actual soluble salt status of soils at the time of examination. This divergence has been established in a number of normal and salt affected soils.

Data now presented show that in saline soils the difference between soil solutions and that of water extracts is particularly marked in the case of certain of the most important constituents, *e.g.*, calcium-sodium ratios, alkali carbonates, phosphate, etc.

As a result, the actual status of the soil indicated by the two methods is vitally different. It is therefore believed that for this and other purposes as shown in foregoing pages the soil solution presents the better basis for consideration. The water extract method probably gives information from which a forecast of the effects of leaching may be deduced.

In order to obtain information as to the primary effects of the presence of sodium chloride in soils on the composition of the soil solution, a normal English (Devon) soil was examined. As was to be expected the presence of sodium chloride resulted in the displacement of the principal bases, and their appearance in the soil solution in increasing proportion. The difference in the case of magnesium was very marked and the high values obtained conform to the recognised importance of magnesium salts in the toxicity of saline soils. The complete disappearance of phosphates from the soil solution following salt treatment falls into line with the fact, observed later on, that in soil solutions from saline soils little or no phosphate occurred.

The appearance of iron, aluminium and manganese in large proportions in the soil solutions at first suggested that perhaps fixation of phosphate by one of the bases explained its disappearance from the soil solution. However, the natural saline soils examined contained 9-10 per cent calcium carbonate, whereas the salted Devon soils had very little reserve calcium carbonate. Addition of calcium carbonate with sodium chloride to this soil resulted, as before, in the disappearance of phosphate from the soil solution, but the latter now contained no iron, aluminium, or manganese. In the natural saline soils no iron, aluminium or manganese occur in the soil solutions. It seems unlikely, therefore, that the depression of phosphate solubility in saline soils can be attributed to the fixation of this kind. It is more probable that fixation is related to the high Ca content of the saline soils.

Soil solution evidently helps in the determination of soil fertility and plant performance. Ratios such as calcium : sodium , calcium : magnesium and sodium : potassium as presented by soil solution are valuable ; *p*H value, phosphate and nitrate content of the soil solution yield most satisfactory data on this point. No such agreement is exhibited by water extracts or even chemical analyses of soil for its total fertility constituents.

Referring to saline and alkaline soils a further point of interest is that alkalinity due to the presence of sodium carbonate shown in soil solution analyses disappears in the water extracts. Presumably at the greater dilution precipitation of calcium and/or magnesium carbonate takes place ; also the high calcium content of water extract tends to suppress dissociation of the sodium clay, and the subsequent formation of sodium carbonate. This came to be true and was supported by evidence obtained under study of (*c*) 'Base-exchange reactions' and the data presented in Tables IV and V. Divergence between the *p*H and sodium carbonate content of soil solutions and of extracts may therefore lead to erroneous conclusions. Sodium carbonate and *p*H values of the soil solutions clearly indicate the dynamic aspects of saline and alkaline soils. There seems no continuity between the variations in values obtained with the different soils from water extracts and that appearing in their displaced solutions.

The combined experience of other workers and the writers points out to the fact that the proportionality between values obtained with soil solution and those with any particular soil water ratio differ from soil to soil and in the same soil as a result of different cultural and irrigational treatments.

It seems, therefore, that the safety limits used in practice of water extracts are purely empirical and their application to different soils is of doubtful value.

Comparison of soil solution and water extracts in the determination of exchangeable calcium and in examination of deteriorated soils has been made. Soil solution as said before gives the most reliable information.

In general the action of salt and/or water in these experiments shows no exception to the fundamentals of base exchange phenomenon.

VII. Summary

No attempt will be made to give a detailed summary of all the findings of the present investigation, the writers being content with drawing attention only to the main conclusions.

Description of a soil solution obtained from a soil of normal moisture content under field conditions is given. In comparison with the usual water extracts (1 : 1, 1 : 5, 1 : 10, etc.) the authors are very definitely of the opinion that the displaced soil solution offers the most reliable information as to the water soluble constituents of soil. Addition of a relatively large quantity of water to a soil must inevitably involve a very considerable shift of the solid-liquid equilibrium, and data obtained from extracts are referable only to the conditions of extraction and have no bearing on the solid-liquid equilibrium under normal field conditions. The nature and proportion of the dissolved constituents as represented by the soil solution and extracts do not show any parallelism in any individual soil. The discrepancies between the two methods become still more apparent when soils of different kinds are examined.

The composition of the displaced soil solution gives more or less a true representation of the liquid phase in soil and therefore forms the nutrient medium of the crop. The relative merits of the soil solution, water extract and acid digestion method in determination of soil nutrient values have been discussed.

Methods of obtaining the soil solution and estimating various bases, fertility ingredients and soil reactions (pH) on micro-scale, as followed in the investigation, have been examined and described.

Possibility of applying soil solution methods to the examination of alkaline and saline soils has been established. Use of water extracts in assessing the proportions of harmful salts is definitely unsatisfactory.

Determination of exchangeable calcium in alkaline and saline soils, soil deterioration in general, has been done through consideration of the displaced soil solution and the water extract in which also the soil solution method establishes its superiority. In general the action of salt and water in these experiments shows no exception to the fundamentals of base-exchange. Use of water extracts may help in forecasting the effects of leachings.

The soil solution approach to the study of some phases of plant nutrition, salt tolerance, and soil behaviour under field conditions, therefore offers some promise and seems worthy of investigation in this connection.

The two minor disadvantages of the soil solution methods are (1) the time required for displacement and (2) the necessity of using a large soil sample than is required by the water extraction and other methods. The time factor is, however, best controlled by experience and care in packing the soil. About ten times (1·5 kilos approximately) as much soil must be used as is required for 1 : 5 water extract. These minor disadvantages are, however, greatly compensated by the recent advances in the development of micro-analyses which offer promise in this direction. A material reduction in the quantity of solution required in the laboratory greatly minimises most of the practical difficulties and also remarkably reduces the time required for evaporation in all the determinations.

VIII. Future scope of work

Authors suggest the use of soil solution methods to students of physical and bio-chemistry in the investigations of—

(1) several soil defects co-related with some of the common diseases of the farm crops,

(2) the movement of soil bases and fertility ingredients,

(3) soil reactions and losses due to drainage,

(4) nutrient requirements of crops, etc.

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COLLOID CONTENT AND THE HYGROSCOPIC POWER OF SOILS

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(With two text-figures)

Many of the important phenomena taking place in the soil are in a large measure due to its colloids. In the present paper a critical study has been made of two important methods of estimation of total colloids in soils comprising both the organic and inorganic colloids. The first section of this paper deals with the results of this work. In section II the soil-moisture relationships for a number of soils containing varying amounts of colloidal material are discussed.

I. Estimation of total colloids

Experimental

The two methods of estimation of total colloids that have been studied are the Hydrometer method due to Bouyoucos [1928] and the Adsorption or Ratio method [Davis, 1925]. In the Hydrometer method dispersion was effected by means of a stirrer worked by a friction driven motor at about 3,000 revolutions per minute after the addition of normal potassium hydroxide solution for deflocculating the colloids. Fifty grams of soil were treated with 350 c. c. of water containing five c. c. of normal potassium hydroxide. A period of thirty minutes was used for complete dispersion. The suspension was made up to 1,000 c. c. and the reading of the hydrometer and the temperature were noted.

In the Ratio method, the adsorption of water vapour by the soils, when exposed to 3·3 per cent sulphuric acid in vacuum desiccators kept at a constant temperature of 30°C. in a thermostat for ninety-six hours, was determined.

Pure colloid was isolated by means of the Sharple's Centrifuge (Cenco, catalogue C. 227, p. 182) from a few soils and the adsorption by the pure colloids was also studied. The centrifuge was hand-driven, the speed of the vertical bowl being about 25,000 revolutions per minute. The suspension of

the colloid passing through the centrifuge was then filtered through a Pasteur-Chamberland filter and the colloid retained by the filter collected [Gile *et al.*, 1924].

The percentage of colloids obtained by both the methods together with the sum of the fine fractions, clay and silt as determined by the International method [Keen, 1931] are given below in Table I [Rao, 1936].

TABLE I

No.	Source	Depth (inches)	Colloids by Hydrometer (per cent)	Absorption at 98 per cent relative humidity moisture (per cent)	Colloids by adsorption (per cent)	Clay (per cent) International method	Clay and silt (International method) (per cent)	Percolation c. c. per hour
1	Adutural . . .	9—24	11·0	12·6	42·0	44·3	59·5	*
2	Anakapalle . .	6—12	12·6	6·7	22·3	19·9	32·1	*
3	Coimbatore (Cotton Breeding Station).	6—18	18·3	6·3	21·0	24·3	30·6	22·0
4	Hagari (West) . .	12—24	35·9	17·9	59·7	45·2	74·2	3·7
5	Hosur F. No. 41 .	6—18	27·7	7·4	24·7	28·6	35·8	16·4
6	Koilpatti (Red) .	9—21	27·1	11·2	37·3	39·4	41·7	23·6
7	Palakuppam . .	6—18	31·3	10·0	33·3	35·1	38·5	*
8	Palur . . .	8—21	17·8	5·8	19·3	17·0	24·3	*

*Not determined.

Percolation rates have been studied for some of these soils by the method due to Puri [1929] with the modification that brass cylinders were used in place of the glass ones described by him. The average values of the percolation rates are included in Table I. They do not show any simple relationship with the clay or the sum of clay and silt. A rapid fall in the percolation rates with increase in the fine fractions was, however, noticeable in the case of Coimbatore, Hagari and Hosur. This lack of correlation between the amount of clay and the rates of percolation is obviously due to the difference in nature and composition of the soil colloids.

Assuming that soils containing 40 per cent and below as the value of the fine fractions, *i.e.*, clay and silt together, to be ' light ' soils and those having above 50 per cent ' heavy ' soils from the results in Table I it appears that :

(*a*) for heavy soils the Hydrometer method gives a lower value of the colloid content than the Ratio method while for light soils, the results obtained by the two methods agree fairly well with the exception of the soil from Anakapalle.

(*b*) the value of the total colloids obtained by the Adsorption method is much higher than the clay fraction in the case of a heavy soil like Hagari, the value of the clay fraction being 45·2 per cent while that of the colloid content is 59·7 per cent. The dispersion of the colloid in the International ammonia method of mechanical analysis is possibly incomplete and a portion of the silt

fraction is composed of aggregates of colloidal material. Hence the phenomenon of adsorption is shared by what is termed ' silt ' in the International method. Alway [1925] believes that a portion of the colloids may be contained even in the sand fraction.

(*c*) the amount of water vapour absorbed by one gram of pure colloid extracted as described above by Sharple's Centrifuge from the black soils of Hagari and Coimbatore is found to be 0·29, a value in agreement with that reported by Robinson [1922] for other types of soils.

Of all the soils examined, the black cotton soils of Hagari and Nandyal show the highest absorption at the different relative humidities (*vide intra*). These soils contain the highest amount of colloid material—a great part of which is inorganic in character.

Further work on the chemical composition of the colloidal material isolated from various soils is in progress.

II. Hygroscopic capacity of soils

The hygroscopic absorption of water by soils which is dependent upon the colloidal content has been studied for some soils at relative humidities of 10, 25, 50, 75, 90 and 98 per cent by the Vacuum desiccator method [Puri *et al.* 1925]. Air-dried soils passed through 2 mm. sieves were exposed in squat form weighing bottles in vacuum desiccators containing suitable mixtures of sulphuric acid and water [J. Ind. Eng. Chem., 1921] to give the required humidities. The period of exposure was ninety-six hours at 30°C. The figures for the moisture absorption for the soils at the different relative humidities are given in Table II.

Table II

No.	Source	Depth (inches)	Moisture absorption at relative humidity					
			10	25	50	75	90	98
1	Adutural . .	0—9	2·0	3·0	5·1	6·7	9·8	10·6
2	Anakapalle . . .	0—6	1·5	2·2	3·5	4·5	6·0	7·9
3	Hagari (West) . .	0—12	3·3	4·9	7·4	9·6	11·6	15·0
4	Hosur F. No. 41 .	0—6	0·5	0·8	1·2	1·6	2·8	5·4
5	Nandyal . . .	0—12	3·2	4·9	7·6	9·6	12·0	14·9
6	Palur . . .	0—8	0·5	0·7	1·1	1·3	1·7	2·4
7	Shemmankuliyur (Coimbatore Dt.)	0—9	0·4	0·5	1·0	1·4	2·2	2·9

In Fig. 1, the values of the hygroscopic capacities of the different soils are plotted against relative humidities.

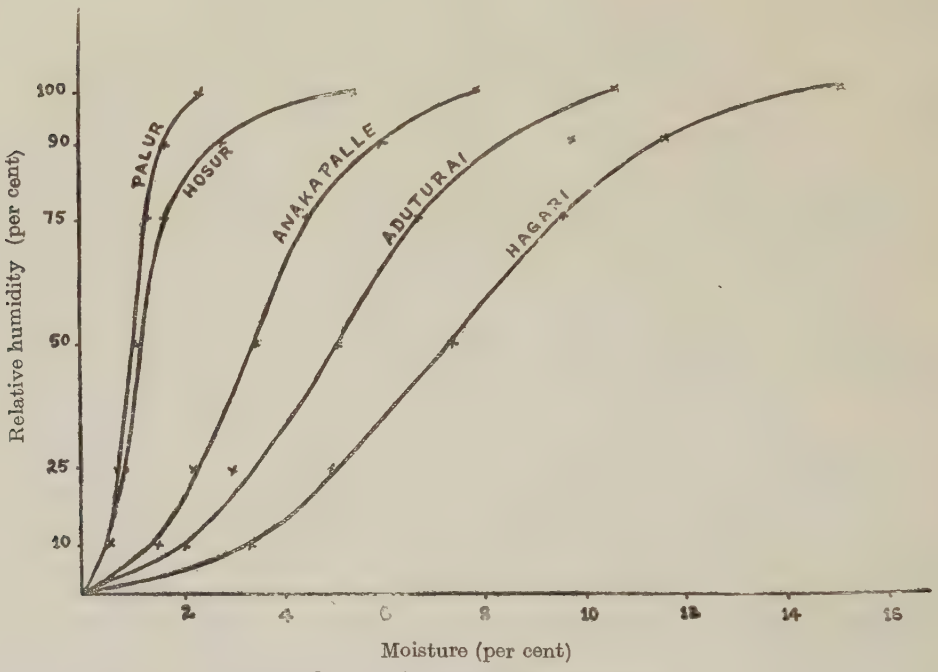

FIG. 1. Vapour pressure curves

(The values for soils Nos. 5 and 7 are not plotted as they overlap with those for soils Nos. 3 and 6 respectively.)

The general shape of the curves is similar for the different soils. They are linear for all soils between 10 and 75 per cent relative humidity. Beyond 75 per cent relative humidity, the curves take a sharp bend tending to become parallel to the moisture axis at higher humidities. The general gradient decreases with increase in the value of the fine fractions.

Progressive absorption of water vapour by soils has been studied at 90, 95 and 100 per cent relative humidities for samples of the Hagari Black soil (East block) taken from plots subjected to normal method of cultivation and from plots which received farmyard manure at the rate of 50 lbs. nitrogen per acre. The moisture content at different periods is given in Table III.

TABLE III

Progressive absorption

Treatment	Layer	Days							
		0	1	2	4	8	12	16	20
At 90 per cent relative humidity									
Control	0-1 ft.	7·73	9·57	10·15	10·67	11·10	11·27	11·32	11·35
	1-2 ft.	8·37	10·08	10·76	11·44	11·90	12·12	12·19	12·21
Farmyard manure . .	0-1 ft.	7·68	9·49	10·21	10·79	11·22	11·39	11·49	11·50
	1-2 ft.	8·20	10·15	10·92	11·62	12·09	12·30	12·38	12·40
At 95 per cent relative humidity									
Control	0-1 ft.	7·65	9·95	10·76	11·66	12·60	13·09	13·45	13·52
	1-2 ft.	8·50	10·69	11·66	12·71	13·68	14·33	14·73	14·83
Farmyard manure . .	0-1 ft.	7·87	10·27	11·15	12·04	12·99	13·62	13·89	13·99
	1-2 ft.	8·41	10·90	11·95	13·00	13·96	14·67	15·09	15·19
At 100 per cent relative humidity									
		0	1	2	3	5	9	13	17	21
Control . .	0-1 ft.	6·52	9·38	10·53	11·20	11·96	12·65	13·65	14·18	14·47
	1-2 ft.	7·11	10·03	11·35	12·16	13·12	14·01	15·08	15·70	16·08
Farmyard manure	0-1 ft.	6·77	9·63	10·81	11·53	12·39	13·39	14·16	14·68	14·98
	1-2 ft.	7·18	10·08	11·44	12·24	13·24	14·15	15·11	15·70	16·04

The absorption of moisture by the soils follows an exponential relationship of the following type :—

$$M = K\,(1 - ae^{-bt})$$

where M is the mositure absorbed by the soil in a period t, K, a and b are constants depending on the nature of the soil and e the base of the Naperian logarithm. The rate of absorption is high at the beginning tending to become constant with increasing time. The results emphasise the importance of specifying the period of exposure whenever 'hygroscopic capacity' of soils is considered.

In Fig. 2 the theoretical values of the moisture content at different periods calculated from the above equation and the observed values are plotted against time. The agreement between the observed and calculated values is closer at lower humidities than at 100 per cent relative humidity. But there is little doubt that the type of absorption follows the exponential relationship given above even at 100 per cent relative humidity.

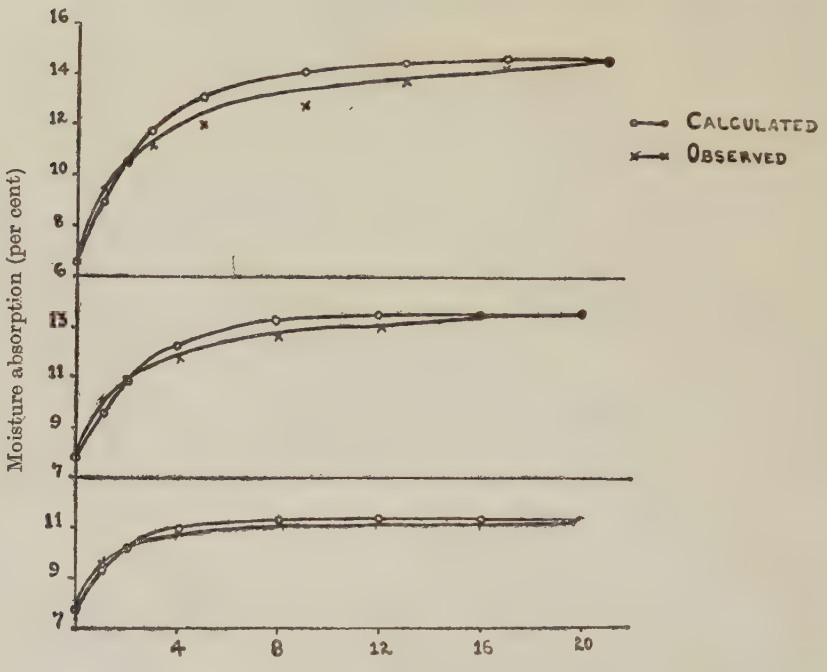

FIG. 2. Progressive absorption of moisture

It is interesting to note that at all the humidities investigated, the soil from the second foot layer invariably absorbed more moisture than that from the first foot layer.

The soil profile at Hagari is fairly uniform to a depth of three feet, with no appreciable variations in the physical composition. The following average values of the mechanical composition by the International ammonia method [Rao, 1937] show that the observed differences in the hygroscopic capacity of the different layers cannot be accounted for by differences in the fine fractions of the soil.

TABLE IV

International ammonia method

	0-1 ft.			1-2 ft.		
	A	B	C	A	B	C
Clay	44.9	45.1	45.1	45.3	45.6	45.0
Silt	17.1	17.4	17.3	19.7	17.1	16.6
Fine sand	15.7	16.4	16.7	15.5	15.5	15.8
Coarse sand	17.3	16.9	16.6	14.8	16.6	17.7
Loss by solution	5.0	4.2	4.3	4.7	5.2	4.9

(A = Control, B = Bunded, C = Ploughed and bunded)

Similarly the SiO_2/R_2O_3 ratios calculated from the authors' figures for chemical composition of the profile down to three feet [Rao, 1936] were 5·72, 5·94 and 5·44 for the layers 0-1 ft., 1-2 ft. and 2-3 ft., respectively. It is clear from these ratios that the top three feet of the profile is uniform and the possibility of the differences in the hygroscopic capacity being due to lower clay and silt values is eliminated. The decrease in the hygroscopic capacity of the surface soil was thought to be due to the fluctuations in the weather conditions which directly influence the top soil, which is subjected more frequently to alternate heating and wetting than the lower layers. The dehydration of the soil colloids is partly irreversible and hence the absorptive capacity of the surface soil is diminished.

Effect of alternate heating and wetting on the absorptive capacity of the soil.— In order to study the effect of alternate heating and wetting of a soil on its absorptive capacity, the absorption of normal soils for water vapour was compared with that of soils alternately saturated with water and dried. The experimental procedure was as follows :—

After obtaining the normal absorption of the soil, an equal weight of water was added. The soil was allowed to air-dry for two days. It was then dried at 100°C. for about ten hours and equal weights of water added and the soil air-dried for two days. This treatment was repeated five times after which the absorption values were again determined. Similar studies were made by Brown and Byers [1935] on soil colloids extracted from some American soils. The absorptive capacities of some soils treated as above at 75, 99, and 100 per cent relative humidities are given in Table V.

TABLE V

Hygroscopic absorption (period of exposure 5 days)

Depth (inches)	100 per cent relative humidity		99 per cent relative humidity		75 per cent relative humidity		Ratio of 100 per cent to 75 per cent	
	A	B	A	B	A	B	A	B
0-6 .	14.78	13.39	14.07	13.70	8.52	7.89	1.74	1.69
6-12 .	15.73	13.90	15.27	14.11	9.29	8.28	1.69	1.68
12-18 .	16.03	13.85	15.33	14.17	9.38	8.23	1.75	1.68

(A =Before treatment, B =After treatment. The figures are the averages of duplicates which agree among themselves.)

At each of the humidities examined there is evidence for the loss in hygroscopic capacity of the soils when alternately wetted and dried. The decrease in the absorptive capacity of the soils after treatment suggests that the lower absorptive capacity of the top layer, observed in the field, is due to the diurnal variation of temperature as well as the fluctuations in weather conditions to which it is exposed.

The exact effect of soil mulch in field operations is yet a matter of discussion. Besides destroying weeds, soil mulch may be beneficial to the extent that it exposes to the air, a layer of soil which is capable of better absorption than the top layer which is constantly exposed to changes in weather conditions. This fresh layer is able to dehydrate the air in immediate contact to a greater extent than the old layer.

Summary and conclusions

1. Two methods of estimating the amount of total colloids in soil have been critically examined with regard to their suitability for some South Indian soils. It was found that the Ratio or Adsorption method gave higher values of the colloid content than the Hydrometer method.

2. Percolation rates did not show any direct correlation with ' clay ' or ' clay and silt ' as determined by the International ammonia method.

3. The absorption of moisture at different relative humidities has been studied for different soils.

4. The amount of moisture absorbed at a given relative humidity varies with time according to an exponential law of the type :

$M = K\,(1 - ae^{-bt})$, where t is the time in days and K, a and b are constants.

5. The moisture retentive capacity of soil has been found to be reduced by alternately heating and wetting it. The bearing of this result on the low moisture retentive capacity of the surface soil compared to that of the subsoil observed in this work has been discussed.

Acknowledgment

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(*a*) (*b*) (*c*)

(*a*) and (*b*) — Mango leaves affected with *Glomerella cingulata* (*Colletotrichum gloeosporioides*)
(*c*) Mango twig affected with *Glomerella cingulata* (*Colletotrichum gloeosporioides*)

SOME STUDIES ON ANTHRACNOSE OF MANGO CAUSED BY *GLOMERELLA CINGULATA* STONEM (S. & V. S.) (*COLLETOTRICHUM GLOEOSPORIOIDES* PENZ) IN THE PUNJAB

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(With Plates XXI and XXII and two text-figures)

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I. Introduction

A report of the occurrence of a disease of mango, which caused drying of leaves and twigs, was received for the first time in February 1934 from a village in the Multan district. After examination of the diseased plants at the spot and in the laboratory, the disease was diagnosed as anthracnose. It was present there in a very serious form. Many young grafted plants, about two to three years old, of varieties imported into that place from other parts of India, were so badly attacked that they ultimately succumbed to the disease.

Later on the disease was found to be prevalent in the districts of Lyallpur, Sheikhupura, Gurdaspur, Jullundur, Ambala and Hoshiarpur. A similar disease of mango due to a species of *Gloeosporium* has been recorded by McRae [1924] from Madras, and due to *Gloeosporium raciborskii* P. Henn. by Uppal, Patel and Kamat [1934] and Stevens and Pierce [1933] from Bombay.

Outside India anthracnose of mango has been recorded in almost all the countries wherever mango is grown. According to McMurran [1914], it was first reported from Porto Rico by Collins in 1903, from Hawaii by Higgins in 1906, from Florida by Fawcett in 1907 and from Cuba by Cardin in 1910. From Uganda it has been reported by Small [1921], from British Guinea by Alston [1925], from Philippines by Ocfemia [1924], from Dominica Republic by Ciferro and Gonyaley Fragaso [1926], from Fiji by Campbell [1927], from Sierra Leone by Deighton [1927], from Guatemala by Popenoe [1919], from Central Andes by Toro [1929] and from South Africa by Doidge [1932].

II. Symptoms of the disease

(*A*) *Macroscopic symptoms*

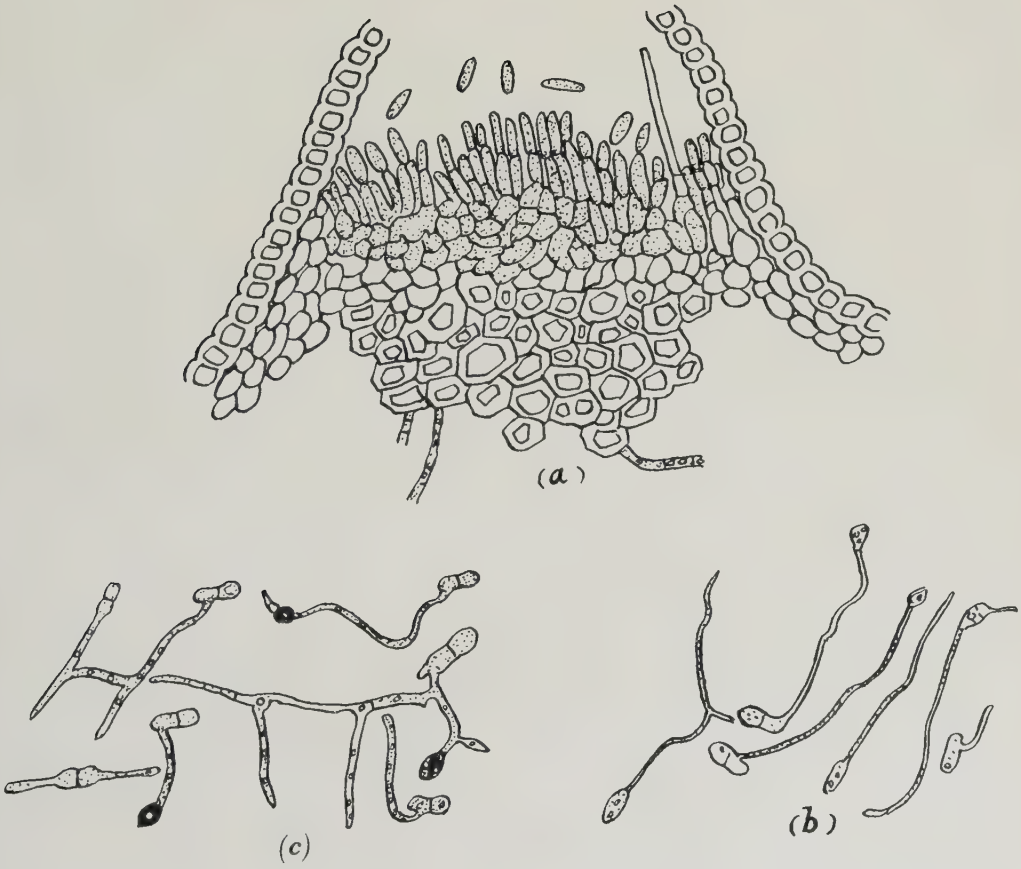
In the Punjab the disease has been observed to attack leaves, petioles, twigs and fruits. On leaves it forms numerous oval or irregular brown spots of very variable size. The spots may begin at the tip or from any other point on the margin or may develop in the centre of the leaf. Under damp conditions the spots grow rapidly, forming elongated necrotic areas which may sometimes result in the rupture of the affected tissue. Young leaves are more severely attacked than old ones.

The petioles, when affected, turn black or grey and the leaves droop down, become dry and ultimately fall off, leaving a black scar on the twig.

On the twigs the disease produces elongated black necrotic areas. The tips of very young branches are first attacked and the twigs go on drying from top to bottom. Under moist conditions all the branches as well as the main stem of young plants may dry out completely. On older plants young thin branches are also similarly affected, but the big branches are not attacked. When the fruits are attacked, black spots develop on them and rot sets in. The blossom blight has not been observed in the Punjab as yet. Two diseased leaves and a diseased twig are shown in Plate XXI.

(*B*) *Microscopic symptoms*

On diseased parts of the plant the acervuli of the causal fungus (*Colletotrichum gloeosporioides*) develop in great abundance. They are irregular and appear as brown to black dots. On the leaves these occur on both surfaces. The acervuli, when mature exude pink masses of conidia under moist conditions. The acervuli are at first sub-epidermal, but later the epidermis ruptures and exposes them. The acervuli measure 80–250 μ. The marginal setae are rare. When present they are dark, fuliginous, cylindrical, continuous (rarely one-septate), 40-90 × 4-6 μ (mean 60 × 5 μ). The conidia are borne on distinct, well developed hyaline conidiophores. The conidia are straight cylindrical or oval, 8-20 × 5-7 μ, hyaline usually with two, rarely one, oil drops. The hyphae of the fungus as seen in transverse section passing through an acervulus are hyaline, septate, full of oil globules. These are both inter and intra cellular. A transverse section passing through an acervulus is shown in Plate XXII.



(*a*) A transverse section passing through an acervulus of *Glomerella cingulata* (*Colletotrichum gloeosporioides*) (conidial stage); (*b*) Spores of *Glomerella cingulata* (*Colletotrichum gloeosporioides*), germinating in water (conidial stage); (*c*) Spores of *Glomerella cingulata* (*Colletotrichum gloeosporioides*) germinating in $\frac{N}{100}$ malic acid.

III. Pathogenicity of the fungus

The fungus was isolated by the usual methods, from diseased leaves and twigs obtained from Multan, Lyallpur and Gurdaspur. The fungus was purified by monosporal culturing. All the isolations were identical.

The potted plants as well as cut twigs of mango were inoculated by spraying the suspension of spores of the fungus grown on oat-meal agar at 25°C. for eight days. The inoculated plants or twigs were kept moist by keeping them covered under bell-jars or under moist screens of gunny sacks for at least four days after inoculation. The results of inoculation are given in Table I. It is clear that the fungus is pathogenic on leaves, petioles, stem and fruits of mango and that the optimum temperature for infection is about 25°C.

Table I

Results of inoculation experiments

Date of inoculation	Kind of plants inoculated	Temperature, at which inoculated (°C.)	Number inoculated	Number infected	Nature of infection
27th July 1934	Potted seedling plants about 15 months old.	32—36	4	*Nil*	*Nil*
31st July 1934	Ditto .	27—30	4	4	80 per cent leaves attacked.
10th August 1937.	Ditto .	27—30	4	4	80 per cent leaves and 40 per cent petioles infected.
23rd August 1934.	(*i*) Potted seedling plants 15 months old.	27—30	4	4	All leaves and petioles infected.
	(*ii*) Grafted plants 2 years old.	27—30	4	4	70 per cent leaves attacked.
25th September 1934	(*i*) Potted seedling plants 15 months old.	24—28	4	4	Leaves, petioles and stem severely attacked.
	(*ii*) Grafted plants 2 years old.		4	4	80 per cent leaves attacked, a few spots on stem also.
13th August 1934.	Cut twigs from seedling plants, lower ends placed in water.	10	6	*Nil*	*Nil*
13th August 1934.	Ditto .	15	6	*Nil*	*Nil*
13th August 1934.	Ditto .	20	6	6	Infection moderate.
13th August 1934.	Ditto .	25	6	6	Infection very severe.
Do. .	Ditto .	30	6	6	Infection moderate.
Do. .	Ditto .	35	6	*Nil*	*Nil*
Do. .	Ditto .	40	6	*Nil*	*Nil*
4th July 1937	Almost mature mango fruits.	25	12	12	Rotted.

IV. Study of the fungus in artificial cultural media

(*A*) *Macroscopic growth features*

(*i*) *Effect of culture medium.*—The fungus was grown on the following culture media at 20°C. The quantities of nutrients are in one litre solution in distilled water.

Oat-meal agar . . . Oat-meal 50 grms., and agar agar 20 grms.

Brown's agar . . . Glucose 2 grms., asparagin 2 grms., K_3PO_4 1·25 grms., $MgSO_4$ 0·75 grms., and agar agar 15 grms.

Brown's starch agar . . Glucose 2 grms., asparagin 2 grms., K_3PO_4 1·25 grms., $MgSO_4$ 0·75 grms., potato starch 10 grms., and agar agar 15 grms.

Richards' agar . . . Sucrose 50 grms., KNO_3 10 grms., KH_2PO_4 5 grms., $MgSO_4$ 2·5 grms., and agar agar 20 grms.

Nutrient glucose agar . . Glucose 20 grms., peptone 10 grms., NaCl 5 grams. extract of meat 4 grms., and agar agar 15 grms.

Potato agar . . . . Peeled potatoes 400 grms., and agar agar 15 grms.

The observations were recorded after twelve days' growth and the various features studied are given in Table II.

Table II

Growth features of the fungus on various culture media

Growth features	Media					
	Oat-meal agar	Brown's agar	Brown's starch agar	Richards' agar	Nutrient glucose agar	Potato agar
Linear colony growth in mm.	88	64	60	103	60	77
Aerial mycelium .	++++	++	++	++++	++++	+
Sporulation . .	++++	+	+++	++++	++	—
Colony colour . .	Salmon buff.	Light salmon orange	Straw-berry pink	Light mineral gray	Flesh pink	Not record-ed

— = *nil*, ++ = moderate, + = trace, +++ = good, ++++ = very good.

(*ii*) *Effect of temperature.*—The fungus was grown on oat-meal and Richards' agars at different temperatures ranging from 5 to 40°C. and the observations were recorded after twelve days. The diameter of colonies of the fungus in both the media at different temperatures is represented in Fig. 1 and the amount of aerial mycelium and sporulation is given in Table III.

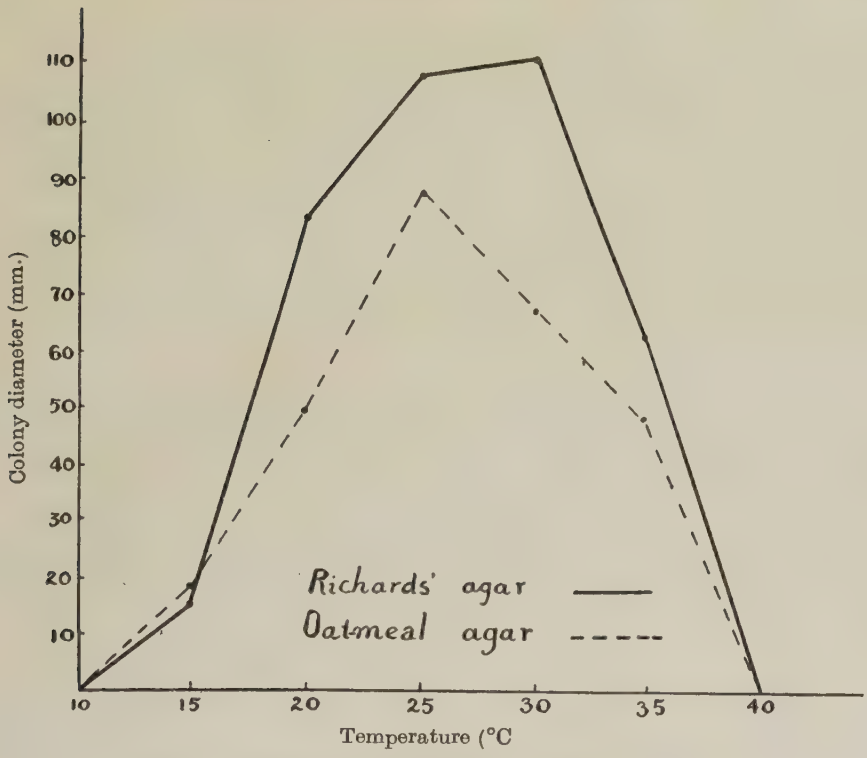


FIG. 1. Effect of temperature upon colony diameter after eleven days

TABLE III

Amount of aerial mycelium and sporulation produced by the fungus at different temperatures

Growth feature	Medium	Temperature (°C.)							
		5	10	15	20	25	30	35	40
Aerial mycelium.	Richards' agar	—	—	+	+++	++++	+++++	++++	—
	Oat-meal agar	—	—	+	++	++	+++	+++++	—
Sporulation	Richards' agar	—	—	—	++	++	++++	+++	—
	Oat-meal agar	—	—	+	+++	++++	+++++	+++	—

— = *nil*, + = trace, ++ = moderate, +++ = good,
++++ = very good, +++++ = abundant.

From Fig. 1, it is clear that the maximum temperature for linear growth of the fungus is between 35 and 40°C. and the minimum is between 10 and

15°C. The optimum temperature is 29°C. for Richards' agar and 25°C. for oat-meal agar, but a close study of the graph reveals that for the culture media in general it seems to be between 25 and 29°C. It is clear from the results given in Table III that the amount of sporulation and aerial mycelium are fairly good on a wide range of temperature, *i.e.*, between 20 and 35°C.

(*iii*) *Effect of hydrogen-ion concentration.*—The medium employed for this study was Richards' agar and the various *p*H values were adjusted colorimetrically by adding normal hydrochloric acid for acid range and sodium hydroxide for basic range. The fungus was grown at 30°C. and observations were recorded after seven days. The linear growth rate at different *p*H ranges is represented in Fig. 2.

The results show that though the greatest linear growth was at *p*H 6·9, the lower ranges up to *p*H 4·2 were all quite suitable for good growth of the fungus. The growth was almost the same from *p*H 4 to 9. At *p*H 3·5 on the acidic side and at *p*H 8·2 on the alkaline side growth fell considerably.

The amount of aerial mycelium was very abundant at *p*H 3·4 to 4·2 and between *p*H 4·2 and 9·0 it was fair, and the amount of sporulation was abundant at *p*H 6·2 to 6·9, fair at *p*H 5·3 and 8·2 and at *p*H below 5·3 and above 8·2 it was scanty or nil.

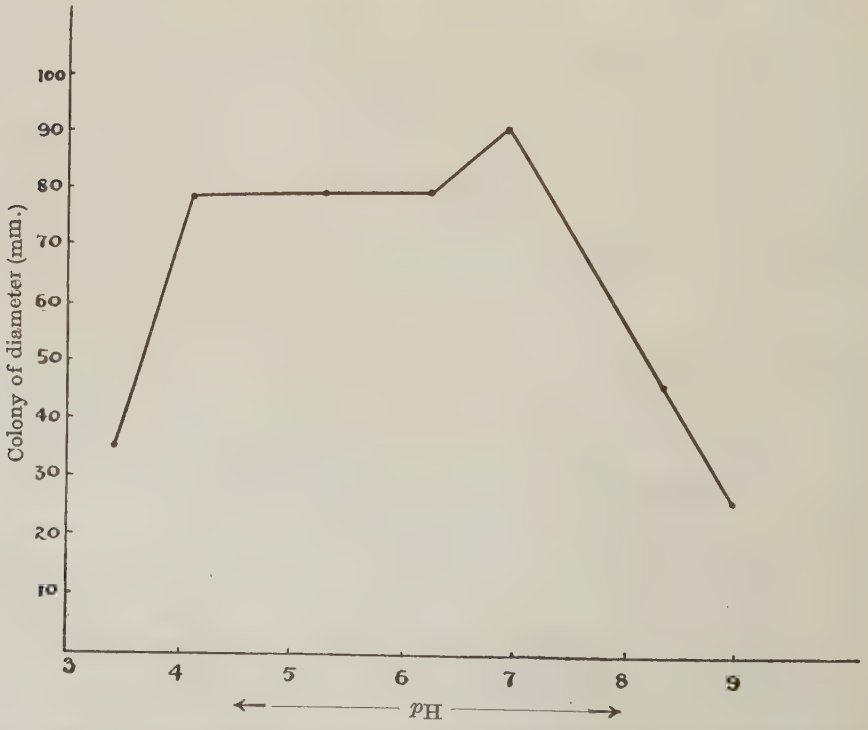


FIG. 2. Effect of *p*H on colony diameter (7 days growth at 20°C. on Richards' agar)

(*B*) *Microscopic growth features*

Size of spores.—The fungus was grown on five different culture media and the spores were measured after eight days' growth at 20°C. The results are recorded in Table IV. The only point worth noting is that in Brown's agar the spores were the shortest. On all the media the spores were hyaline and continuous.

TABLE IV

Size of spores in different culture media

Culture media	Length in μ		Width in μ	
	Limits of variation	Mean	Limits of variation	Mean
1. Oat-meal agar . . .	8·8—26·0	15·2	3·2—6·8	5·2
2. Brown's agar . . .	8·8—18·0	12·8	3·2—6·0	4·4
3. Brown's starch agar . .	9·2—18·8	14·4	3·2—7·2	5·2
4. Richards' agar . . .	8·8—24·4	13·6	4·0—6·0	4·8
5. Nutrient glucose agar .	8·8—24·8	15·2	3·2—5·6	4·8

The effect of temperature and hydrogen-ion concentration on the size of spores was also studied in some detail but neither of these was found to have any appreciable effect.

(*C*) *Germination of spores*

(*i*) *Mode of germination.*—The spores of the fungus when sown in drops of distilled water at 20°C. began to produce germ tubes after about six hours and about 7 per cent of the spores became one-septate. Germination went on increasing till after about twenty-four hours it reached a figure of about 70 per cent. Germ tubes generally came out from the ends of spores but occasionally these developed from the middle of the spore length. The germ tubes elongated rapidly and about twelve hours after their formation began to develop appressoria at their ends. The appressoria were knob—or club-shaped structures with a dark thick wall. Often more than one appressorium was formed on a single germ tube. In such cases a hyphal branch was given out from the first formed appressorium and this in turn bore another appressorium.

In *N*/100 malic acid the mode of germination resembled that in water, the only difference being that in this solution about 50 per cent of the spores became one-septate during germination.

(*ii*) *Effect of temperature on germination.*—The germination of spores was studied in water at different temperatures varying from 5-40°C. The spores for the purpose of this study were taken from a fourteen days' old culture of the fungus on oat-meal agar at 20°C. Observations were recorded after twelve, twenty-four and thirty-six hours of sowing and the results are given in Table V.

TABLE V

Germination of spores at different temperatures

Temperature (°C.)	Percentage of germination after			Percentage of of one-septate spores at the end of 36 hours	Percentage of spores which were bearing appressoria at the end of 36 hours
	12 hours	24 hours	36 hours		
5	0	0	0	0	0
10	0	0	0	0	0
15	0	5	9	0	2
20	42	55	63	4	48
25	73	75	85	7	63
30	38	40	45	3	18
35	9	9	11	0	0
40	0	0	0	0	0

From the results given in Table V it is clear that the optimum temperature for germination of spores is 25°C., the maximum between 35 and 40°C. and the minimum between 10 and 15°C.

V. IDENTITY OF THE CAUSAL FUNGUS

Three species of *Gloeosporium*—*Gloeosporium mangae* Noack, *Gloeosporium mangiferae* P. Henn. and *Gloeosporium raciborskii* P. Henn.—have been described on mango [Saccardo, 1902], but from their descriptions it is impossible to separate them. The same view was expressed by Shear and Wood [1913] and the authors also hold the same view. The limits of variation in the size of spores as given in Saccardo are $12\frac{1}{2}$-17 × 3-$3\frac{1}{2}$, 10-16 × 4-$5\frac{1}{2}$ and 12-16 × 4-5 μ for *Gloeosporium mangae*, *Gloeosporium mangiferae* and *Gloeosporium raciborskii* respectively. The limits of variation in the size of spores of the species of *Gloeosporium* described in this paper are 8-20 × 5-7 μ on the host and 8·8-26 × 3·2-7·2 μ in artificial culture media. Thus it is clear that as regards spore size all the three described species of *Gloeosporium* from mango and the one occurring on mango in the Punjab cannot be separated.

Further according to Ocfemia and Agati [1925], Nolla [1926] and Small [1926], the species *Gloeosporium mangiferae* P. Henn. is identical with *Colletotrichum gloeosporioides* Penz. and is considered by Shear and Wood [1913]

and Ocfemia and Agati [1925] to have *Glomerella cingulata* Stonem (S. and VS.) as its perfect stage. The fungus which causes anthracnose of mango in the Punjab should, therefore, be called *Glomerella cingulata* Stonem (S. and VS.) (*Colletotrichum gloeosporioides*).

VI. Modes of perennation of the disease

In order to study the modes of perennation of the disease the following experiments were conducted :—

1. Viability of the fungus in detached diseased twigs and leaves

Twenty diseased twigs and forty leaves affected with anthracnose were removed from mango trees in February 1934 and were kept on the surface of soil in the open at Lyallpur. The viability of the fungus in these twigs was tested from time to time. The results obtained were :—

(*i*) Even after two years' exposure to open weather conditions, the fungus *Glomerella cingulata* (*Colletotrichum gloeosporioides*) could be isolated from the diseased bits of twigs. Seventy per cent of the spores of the fungus borne in acervuli on the twigs were viable. After this period these twigs rotted and were eaten away by white ants.

(*ii*) In the diseased leaves the fungus remained viable for fourteen months. After this period the leaves rotted completely.

As fresh acervuli also developed on diseased twigs and leaves during the period of exposure, it cannot be said whether the viable spores were from the original or fresh acervuli.

(*iii*) Inoculations were made with spores taken from these diseased twigs and leaves on young mango plants. Typical symptoms of the anthracnose disease were produced.

2. Viability of the fungus in diseased twigs persisting on the trees

In nature the infected leaves fall off, but the diseased twigs even after death remain attached to the plant. Twenty diseased twigs on mango trees were marked in February, 1934 and were examined in September 1935, with the following results :—

(*i*) The acervuli were abundant on the marked dead twigs and 80 per cent of the spores in them were viable as proved by germination tests. Fresh acervuli go on appearing on dead twigs persisting on the trees.

(*ii*) Inoculations were made with spores taken from these twigs on young mango plants. These caused the typical anthracnose disease.

Thus from the results of the above experiments it is concluded that so far the disease has been found to perennate by the following methods :—

(1) In the detached diseased twigs and leaves which remain lying on the surface of soil.

(2) In the diseased twigs which may remain attached to the trees.

VII. Methods of control

It is clear from the foregoing account that in order to avoid fresh infection, the sources of infection mentioned therein should be eliminated. The diseased mango leaves, twigs and fruits lying in the garden should be collected and all the diseased twigs on the trees should be pruned away and all such refuse should then be burnt. It is also to be remembered that to achieve good results it is necessary that all the owners of mango gardens in an affected locality should take action simultaneously and co-operatively in their respective gardens. As in practice the total suppression of these sources of infection is not possible, even if these recommendations are followed, the disease cannot be completely controlled, though it can be reduced considerably. Therefore in addition plants have to be sprayed with some fungicide. Trials conducted at Multan on young grafted mango plants showed that spraying the plants with 3 : 3 : 50 Bordeaux mixture three times a year—in February and then in April and September—in addition to the removal of the potential sources of infection above referred to was effective in controlling the disease. Spraying experiments for the control of the disease on plants of bearing age have still to be conducted. In the meantime, however, the following recommendations can be safely made for the control of the disease :—

(1) Remove all the diseased mango leaves and twigs lying about in the garden.

(2) Prune all the diseased twigs and burn them. The cut ends of big branches should be coal-tarred.

(3) Spray the plants with 3 : 3 : 50 Bordeaux mixture three times a year during February, April and September.

VIII. Summary

1. Symptoms of anthracnose disease of mango have been described.

2. The fungus causing the disease has been identified as (*Glomerella cingulata* Stonem (S. and VS.) (*Colletotrichum gloeosporioides* Penz.)

3. Inoculation experiments have shown that the fungus is pathogenic on leaves, petioles, stem and fruits of mango and that the optimum temperature for infection is about 25°C.

4. Effect of different environmental conditions such as nature of medium, acidity of medium and temperature on the growth features of the fungus has been studied.

5. Germination of spores of the fungus has been studied at different temperatures and the mode of germination of spores has been described.

6. The disease has been found to perennate by the following methods :—

(1) In the detached diseased twigs and leaves which remain lying on the surface of soil, and

(2) In the diseased twigs which remain attached to the trees.

7. The following measures for the control of the disease have been suggested :—

(1) Remove all the diseased mango leaves and twigs lying about in the garden.

(2) Prune all the diseased twigs and burn them. The cut ends of big branches should be coal-tarred.

(3) Spray the plants with 3 : 3 : 50 Bordeaux mixture three times a year during February, April and September.

The authors feel indebted to Rai Sahib Jai Chand Luthra, I.A.S., Professor of Botany, Lyallpur, for helpful suggestions and providing facilities during the course of this work. They also feel grateful to M. Ali Mohd., artist for drawing Plate XXI.

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THE PRACTICABILITY OF BIOLOGICAL CONTROL IN THE LAC INDUSTRY

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I. Introduction

The production of lac, the raw product from which shellac, seedlac, and button lac are manufactured is virtually a monopoly in the hands of India. Only approximately 12 per cent of the world's production of stick lac comes from outside India ; of this, roughly 80,000 maunds per annum are produced in Burma, and 60,000 in Indo-China and Siam. The greater part of this *ex*-India production is imported into India and manufactured in this country.

The production of stick lac in India during the last ten years (*i.e.*, 1928-1937) has varied from 9 to 16¼ lakhs of maunds per annum and has averaged 11½ lakhs per annum.

Lac is the resinous secretion of an insect known as the lac insect, *Laccifer lacca* Kerr, which is a member of the Super-Family Coccidae of the Order Hemiptera. This insect derives its nourishment from the sap of certain species of trees and shrubs on which it is parasitic. The majority of these belong to the Leguminosae, and are called lac hosts. There are two varieties of *L. lacca* in the major lac-growing areas, each of which passes through two complete life-cycles during the year, one life-cycle corresponding to a lac crop. These varieties are termed the Rangeeni variety whose two crops are called the *Katki* and *Baisakhi* and the Kusmi variety whose two crops are termed the *Aghani* and *Jethwi*.

Certain lac-growing areas, as for example the Sadar Division of the Palamau District of Bihar, produce almost entirely *Katki* and *Baisakhi* lac and may be termed predominantly Rangeeni areas. The Singhbhum District and parts of the Ranchi District of Bihar, on the other hand, produce mainly *Aghani* and *Jethwi* crops and may be termed predominantly Kusmi areas. Areas in which all four crops are to be found, may be referred to as combined areas.

II. Damage to the lac crops

Damage to the lac crops is of two kinds, both of which occur simultaneously :—

(*a*) Damage due to causes other than insects ;

(*b*) Damage directly due to enemy insects.

(*a*) The former accounts for not less than 30-40 per cent of the original settlement, and is in part unavoidable, as larval settlement is of such density that if mortality did not occur there would be no room for the development of all the cells. It is in part due to climatic conditions, such as intense heat, frost, etc. Part, however, is reducible, being due, for example, to faulty cultivation methods such as incorrect pruning, infection of host trees for crops to which they are not suited, or infection with unsuitable strains of lac.

(*b*) The damage done by insect enemies is approximately 30-40 per cent of the lac cells.

The actual lac crop obtained is approximately 1/4th -1/3rd of the possible hypothetical crop. Of the original settlement 30 per cent is male which takes no practical part in lac secretion. Although only as few as 15-20 per cent of the original settlement may survive to crop maturity, 30-40 per cent, however, takes an appreciable part in lac secretion.

Damage by insect enemies is caused by two main classes of enemies—the parasites and the predators.

III. Damage to the lac crops by parasites

Parasite enemies belong to the Super-Family Chalcidoidea and eight species commonly occur in the major lac-growing areas. These are :—

Encyrtidae—

Parecthrodryinus clavicornis Cam.

Erencyrtus dewitzi Mahd.

Tachardiaephagus tachardiae How.

Tachardiaephagus somervilli Mahd.

Eupelmidae—

Eupelmus tachardiae How.

Aphelinidae—

Coccophagus tschirchii Mahd.

Marietta javensis How.

Eulophidae—

Tetrastichus purpureus Cam.

The damage done by this class of enemy has been shown to be small at Namkum, amounting over seven years to only 4·8 per cent of the lac cells, with an average maximum of only 9·9 per cent.

IV. Damage to the lac crops by predators

A number of predators of the lac insect is known and includes *Ephestia* sp., *Eublemma scitula* Rambr., *Pyroderces falcatella* St., *Chrysopa* sp., etc. Practically the whole of the predator damage to lac, however, is caused exclusively by the larvae of the following :—

1. *Eublemma amabilis* Moore. (Noctuidae)
2. *Holcocera pulverea* Meyr. (Blastobasidae).

The damage by these predators has been shown to amount to 30-35 per cent of the lac cells. It will be seen, therefore, that practically the whole of the insect damage to lac crops is caused by this class of enemy.

Not only is the quantity of lac produced affected by predator enemies, the quality is also lowered by the presence of predator larvae and pupae and their frass. Manufacturing costs are also affected by them because the yield of seed lac on scraped lac is lowered by the presence of the tunnels bored by the predator larvae and by the frass produced by them.

V. Biological control

(*a*) *Biological control of lac parasites*

Three species of hyperparasites of lac parasites have been observed ; in each case, however, the hyperparasite species is in primary function a lac parasite. These species are :

1. *Tetrastichus purpureus* Cam. (Eulophidae.)
2. *Eupelmus tachardiae* How. (Eupelmidae.)
3. *Marietta javensis* How. (Aphelinidae.)

The average percentage hyperparasitism over five years amounted to only 3·6, with an average maximum of only 10·1. In view of this low figure and the fact that the three species are, in primary function, lac parasites, it is clear that biological control of lac parasites is not feasible. In view, however, of the small amount of damage done by lac parasites, this is not of major importance.

(*b*) *Biological control of lac predators*

It is clear, therefore, that biological control in the lac industry actually means biological control of the lac predators, and *E. amabilis* and *H. pulverea* being the two species of major importance as lac predators, it is on the biological control of these species that attention must be concentrated. The following parasites of *E. amabilis* and *H. pulverea* have been bred at Namkum.

1. Parasites of both *E. amabilis* and *H. pulverea*—

Microbracon hebetor Say (Braconidae), larval ecto-parasite, Introduced.

Brachymeria tachardiae Cam. (Chalcididae), pupal endo-parasite.

2. Parasites of *E. amabilis*—

Microbracon greeni Ashm. (Braconidae), larval ecto-parasite.

Aphrastobracon flavipennis Ashm. (Braconidae), larval ecto-parasite. Rare.

Elasmus claripennis Cam. (Elasmidae), larval ecto-parasite.

3. Parasites of *H. pulverea*—

Apanteles tachardiae Cam. (Braconidae), larval endo-parasite.

Pristomerus testaceicollis Cam. (Ichneumonidae), larval endo-parasite.

Eurytoma palidiscapus Cam. (Eurytomidae), pupal endo-parasite.

Periseriola sp. (Bethylidae), larval ecto-parasite.

Elasmus albomaculatus Garh (Elasmidae), larval ecto-parasite. Very rare.

4. Suspected parasites of *H. pulverea*—

Apanteles fakrulhajiae Mahd. (Braconidae), larval endo-parasite.

Chelonella cyclopora Franz. (Braconidae), larval endo-parasite.

Of these parasites of *E. amabilis* and *H. pulverea*, all are indigenous, except *Microbracon hebetor* which is unknown in the major lac-growing areas. Among them, two are of major importance as parasites of lac predators, and can easily be reared in large numbers in the laboratory, these are *Microbracon greeni* Ashm. and *Microbracon hebetor* Say.

Microbracon greeni is an indigenous ecto-parasite of the larva of *E. amabilis*, it can easily be bred in the laboratory, and under field condition is monophagous. The average percentage parasitism throughout the year amounts to approximately 10. This low figure appears to be due to a very great scarcity of host larvae in sufficiently advanced stage for parasitism in the field at certain times of year. As a result of this, the percentage parasitism is very small at such times and the presence of adult parasites in the field very low. When the host density increases, as it does rapidly, the parasite population is still low and it is only some considerable time later that the parasite density increases to a similar extent. Laboratory results indicate that releases of artificially bred adults at such periods would greatly increase the average percentage parasitism.

Microbracon hebetor is an ecto-parasite of both the larvae of *E. amabilis* and of *H. pulverea*. It does not at present occur in the major lac-growing tracts. Adults were obtained from Ceylon by the senior author, where it occurs as a parasite of *Ephestia kühniella* Zell. From these adults a thriving colony has been built up at Namkum. *M. hebetor* can be bred easily in the faboratory and has a number of alternative hosts all of which are pests of

greater or less importance, on which it can breed when host larvae in lac are scarce. Laboratory experiments indicate promising results from the introduction of this Braconid on a large scale in major lac-growing areas. Small-scale field experiments so far carried out show that *M. hebetor* is able to colonise and breed under field conditions.

VI. Proposed large-scale field experiments

The Indian Lac Research Institute has taken over an area situated in the Ranchi District about eleven miles distant from Namkum. This area is predominantly Kusmi, though it contains a small number of hosts producing Rangeeni lac.

Into this area, introductions of *Microbracon greeni* and *Microbracon hebetor* will be made. Regular sampling will be carried out with the object to discover—

(*a*) The effect of periodic releases of *M. greeni* on its population density and on the percentage of hosts parasitised.

(*b*) Whether *M. hebetor* can be artificially introduced and established.

(*c*) The natural population density of *M. hebetor* and percentage of hosts parasitised after establishment.

At the maturity of each crop, a portion will be selected as brood lac (*i.e.* seed for the infection of a new crop), and of this, part will be transferred to another isolated area and used to infect a number of trees for a further crop. Into this second area artificial introductions of these Braconids will not be made. The object being to determine whether—

(*a*) The population density and percentage of hosts parasitised by *M. greeni* can be maintained at a high level by means of adults transferred from one area to another *via* brood lac from an area where periodic liberations of *M. greeni* have been made.

(*b*) Whether *M. hebetor* can be transferred from an area in which liberations have been made to a second area by means of brood lac, and if so, the natural population density and percentage of hosts parasitised in the second area.

It has been thought worth while to place on record the present position as regards these two Braconids, in a predominantly Kusmi area in order to have figures against which to compare the figures from the biological control area chosen.

TABLE I

Density of host population, average percentage parasitism, and density of parasite population, Microbracon greeni *Ashm. per 100 ft. lac in a predominantly Kusmi area, average of seven years (1928-35)*

Month	Presence of *M. greeni* adults per 100 ft. lac	Aghani crop		Jethwi crop	
		Presence of *E. amabilis* larvae in 100 ft. lac	Per cent parasitism	Presence of *E. amabilis* larvae in 100 ft. lac	Per cent parasitism
July	15·4	264 young	0·0	688	7·1
August	6·2	1,704	0·5	Crop cut in June-July re-infected in the following February.	
September	73·4	1,140	8·7		
October	49·0	648	18·2		
November	16·4	744	7·3		
December	11·0	684	15·3		
January	29·0	588	25·4		
February	45·5	336	36·0	0	0·0
March	10·1	252	50·0	168 young	0·0
April	2·1	Crop cut in February-March re-infected the following July.		420 young	0·0
May	1·8			420 young	5·8
June	2·8			288	21·2

(*a*) *Microbracon greeni*

Table I, which is taken from a paper on this species at present in preparation for publication, records the monthly density of *M. greeni* adults and the percentage parasitism in a predominantly Kusmi area, calculated over the seven years, 1928-1935, per 100 ft. of lac in the field. It will be seen that the average number of adults per month per 100 ft. of lac is 22, and the average monthly percentage parasitism 16·3.

The proposed times of liberations of *M. greeni* adults in the field are early August, November and early in May. (This matter is fully discussed in the paper in preparation.)

(*b*) *Microbracon hebetor*

The present density of *M. hebetor* adults in the field and the percentage parasitism are both *nil*.

VII. Recently discovered egg parasites of lac predators

Recently two Trichogrammid egg parasites of the eggs of *E. amabilis*, *H. pulverea* and of a Lycaenid *Tarucus theophrastus* L. have been discovered and have been identified by the Imperial Bureau of Entomology as *Trichogrammatoidea nana* Zehnt and *Trichogramma minutum* Riley. Their potential value in control is great, as they attack their host in the egg stage before any damage has been done. They appear to limit their attack, however, to predator eggs, before the lac encrustation has become thick and continuous and covered with white waxy filaments. In addition, neither *E. amabilis* nor *H. pulverea* lay their eggs in masses. It is at present too early to say anything as regards these two species other than to suggest that their importance in control may be great.

Acknowledgments

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Summary

1. Insect damage to the lac crops is of two kinds, that due to parasites and that due to predators. The damage done by parasites is small, amounting to only 4·8 per cent ; that due to predators is serious and amounts to 30-40 per cent of the lac cells.

2. Biological control of lac parasites is not feasible ; this is not of major importance as the damage done by them is small.

3. Predator damage is practically entirely caused by the larvae of *Eublemma amabilis* and *Holcocera pulverea*. Biological control in the lac industry amounts to the control of these species.

4. Of the parasites of *E. amabilis* and *H. pulverea* the more important are *Microbracon greeni* and *Microbracon hebetor*. The former is an indigenous parasite of the larva of *E. amabilis*. The latter is an introduced parasite of the larvae of both *E. amabilis* and *H. pulverea*.

5. The average percentage parasitism by *M. greeni* is approximately 10 and the average presence of adults in the field 22 per each 100 ft. of lac. The parasite density becomes very small at certain times of year when hosts are scarce, when the host density increases the parasite density does not increase with the same rapidity. Laboratory tests indicate beneficial results from the release of artificially reared adults at such critical periods.

6. *M. hebetor* does not at present occur in the major lac-growing areas. Laboratory tests indicate that its introduction would be attended by beneficial results.

7. A brief account is given of an experiment that has been started to test the economic value of these Braconids on a field scale.

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TWO NEW CHALCIDOID PARASITES OF THE LINSEED MIDGE, *DASYNEURA LINI* BARNES

I. BIOLOGY AND MORPHOLOGY OF *SYSTASIS DASYNEURAE* MANI

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(With Plate XXIII)

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I. BIOLOGY AND MORPHOLOGY OF *SYSTASIS DASYNEURAE* MANI—

1. Introduction

THE linseed midge, *Dasyneura lini*, was described by Barnes [1936 from material bred from linseed flower buds at Pusa, Bihar, in 1933. A detailed account of its biology has been published by Pruthi and Bhatia [1937] who consider that, in view of the rapid expansion of linseed cultivation in India, this insect is likely to prove an important pest in the future. This forecast is proving to be true, as during the last year reports have been received by the Imperial Entomologist about the seriousness of this pest from several provinces, *e.g.*, the Punjab, Sind, Central Provinces, Delhi, etc.

While this pest was under investigation at Pusa in 1935, occasionally the writer found some ' stumpy ' eggs in the linseed buds, which were quite different from those of the midge, and the larvae hatched therefrom could not be bred on the plant. Similar eggs were also found at Karnal (Punjab) in 1937, which on breeding proved to be those of a Chalcidoid parasite of the midge larvae. The material of *Dasyneura lini*, received recently from Nagpur (Central Provinces) and Sakrand (Sind), has been also found parasitized by the same parasite. The parasite is new to science and is described in part II as a new species under the name *Systasis dasyneurae* by the second author. From the linseed material obtained from Karnal, another chalcidoid also emerged belonging to an undescribed genus, the status of which could not be determined but it is presumably a hyperparasite. This new genus and species are also described in part II. An account of the biology and morphology of the primary parasite, *Systasis dasyneurae*, forms the subject of this part.

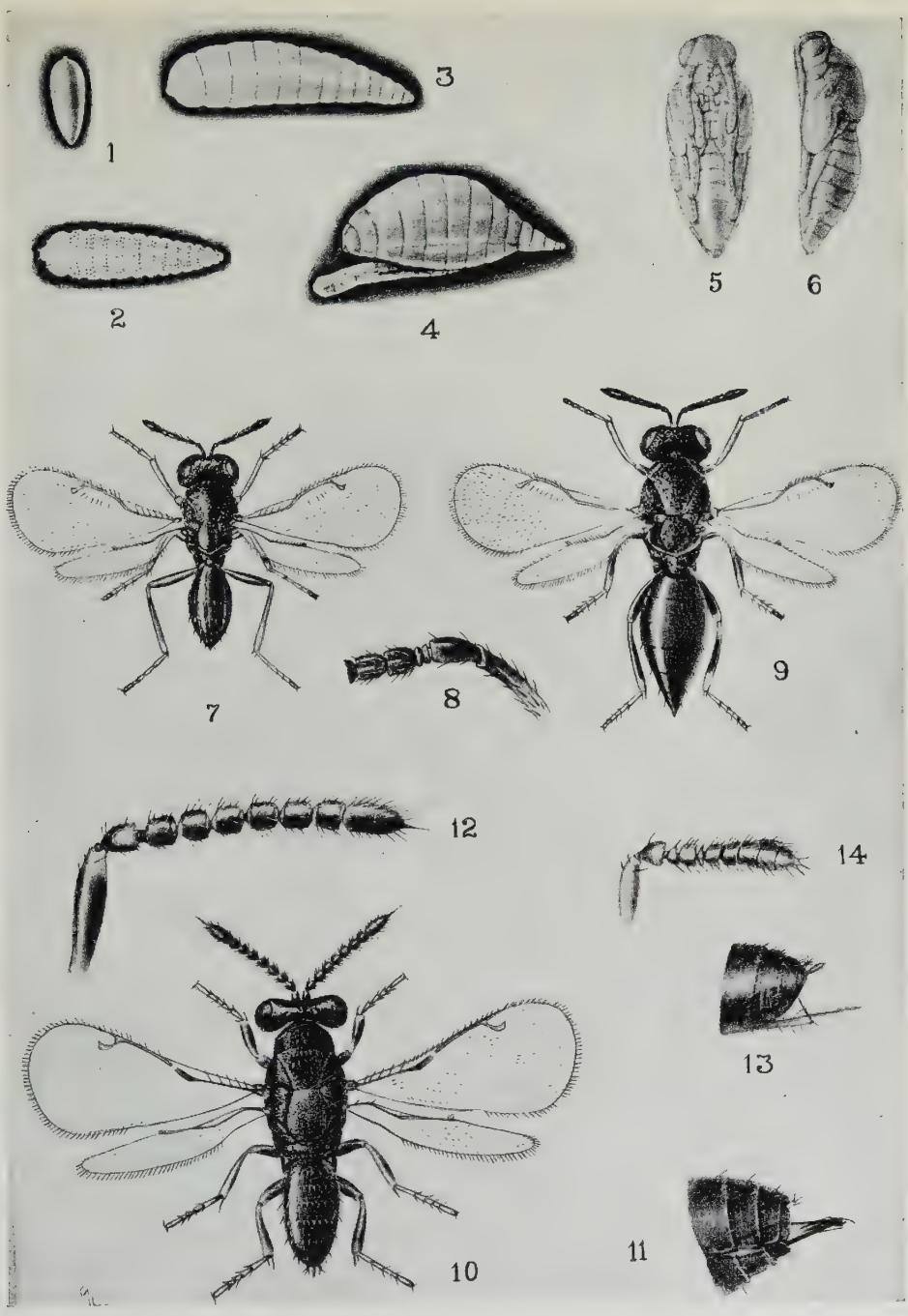
Our sincere thanks are due to Dr. Hem Singh Pruthi, Imperial Entomologist, for facilities for work and valuable suggestions and to Mr. P. Narayanan, the staff artist, who executed the plates with his usual skill under our supervision.

2. Life-history and description of immature stages

Oviposition.—The eggs are laid inside the crumpled and unopened buds of linseed containing well-developed host larvae. The fact that these eggs are invariably found in flower buds already containing almost full-grown larvae of *Dasyneura lini* shows that the parasite possesses not only keen sense of selection but is also capable of distinguishing the affected buds from the healthy ones and further of selecting buds containing host larvae of the right age. Eggs are laid singly but are not necessarily deposited on the host, being more often found on the corolla or stalks and anthers of stamens. They are usually found between the folds of corolla, occasionally on the ovary and anthers, but very rarely outside the corolla in the folds of sepals. Not more than one egg was found in one flower.

Egg.—When freshly laid, the egg is almost transparent, but soon becomes translucent. A little later, a pale yellow band appears all round the egg (Plate XXIII, fig. 1). Just before hatching, the egg becomes darker. It is of a conical or stumpy appearance. At its broad end, the egg is provided with a minute stalk. The surface is marked with microscopic round spots. On an average of twelve readings, the egg measured 0·37 mm. long and 0·13 mm. broad at the thick end.

At a constant temperature of 18°C., the egg stage lasts two to three days. In nature, during February when the nights are rather cool (temperature 15°-18°C.) the incubation period is three to four days. During April (field temperature 25°-29°C.) the eggs hatch in twenty-four to twenty-eight hours.



FIGS. 1—9. *Systasis dasyneurae*, sp. nov.

FIG. 1. Egg (×60). FIG. 2. Grub, freshly hatched (×120). FIG. 3. Grub, half developed (×120). FIG. 4. Grub, full developed, on the body-remains of host (×30). FIG. 5. Pupa, ventral view (×30). FIG. 6. Pupa, lateral view (×30). FIG. 7. Adult parasite, male (×35). FIG. 8. Antenna of male parasite, highly magnified. FIG. 9. Adult parasite, female (×35).

FIGS. 10—14. *Ecrizotomorpha taskhiri*, gen. *et* sp. nov.

FIG. 10. Adult, male (×50). FIG. 11. Tip of abdomen of male, highly magnified. FIG. 12. Antenna of male, highly magnified. FIG. 13. Tip of abdomen of female, highly magnified. FIG. 14. Antenna of female,

Grub.—The grub hatches out of the broad end of the egg, where first of all a crescentic slit appears. The young grub may then be seen struggling in the egg for about three quarters of an hour. By this time the head protrudes from the slit and in a few seconds the grub wriggles out completely. The grub immediately after hatching (Plate XXIII, fig. 2) is colourless and almost transparent with the exception of a pale yellow patch (due to the embryonic food inside) extending from the mesothoracic segment to about the fifth abdominal segment. The body consists of the usual three thoracic and ten abdominal segments. It measures about 0·37 to 0·40 mm. long and 0·10 to 0·11 mm. broad. Thus, although the body length of the grub is slightly more than that of the egg, the general shape of the egg is maintained in the grub. The head capsule is large, broadly rounded anteriorly, with strong mandibles in front. The thorax is as broad as, or slightly broader than, the head capsule, the grub having the maximum breadth in the region of the third thoracic segment. The abdomen gradually tapers in the posterior region, the anal segment being narrowly rounded. All the thoracic and abdominal segments are covered with three rows of minute setae, numbering twelve to fourteen per row in the first six segments, but getting fewer as the segments become narrower.

It has been mentioned above that the eggs are almost always laid in buds which already contain well-developed host larvae. Having ensured this, the parasite does not take further care to lay its egg on the body of the host. Therefore the young grub on hatching has sometimes to make a long search for the host. The young grub is extraordinarily hardy and active. It was found capable of wandering about for over twenty-four hours after hatching in search of the host. The terminal portion of its body seems very sensitive and is constantly kept moving as if to serve the purpose of feelers. On coming across a grown-up host larva, it feels it with the last abdominal segment and at once sticks to it. In the initial stages of its growth, the parasite grub makes a minute hole in the body of the host and feeds only on the body juice without injuring its essential organs. At this time its colour is light yellow and the body becomes more elongate, length being about four times the breadth (Plate XXIII, fig. 3, length 0·5 mm., breadth 0·13 mm.). Gradually the thoracic segments increase in size and become conspicuously broader than the head capsule. Later on, the grub begins to feed on the whole body contents of the host leaving only the outer body wall intact. At this stage, it acquires the pinkish orange colouration of the host and its shape also undergoes a considerable change. The body swells up very much in the middle, the first and second abdominal segments marking the maximum width of the larva which is about 0·83 mm. When full grown, the grub measures about 1·8 mm. in length (Plate XXIII, fig. 4). Posterior to the second abdominal segment, the body narrows down almost uniformly, the fifth abdominal segment behind and the head in front having almost equal thickness. The last four abdominal segments remain narrow and continue to move actively and function as feelers.

The first appearance of the swollen pink stage is fairly soon, *viz.*, about four to six days after hatching at 18°C., provided the food supply is abundant. After another four days the grub acquires the maximum size and is full grown. At this time it stops feeding, the pink food inside gets digested and the body colour becomes lighter—first orange yellow, then almost yellow, with a tinge of orange. It contracts, lies motionless for about forty-eight hours and evacuates its excreta which are seen deposited near the posterior end of its body. It finally transforms into a pupa. The total larval period is about twelve to fifteen days (average of ten observations being 13·1 days) at 18°C.

During the entire larval period, the parasite grub consumes three to four host larvae and this number is usually available in one linseed bud. When the parasite egg is laid in buds containing less than three host larvae, it probably gets starved or yields small-sized adults, as it is not capable of moving from one bud to the other. On the other hand, where more than four larvae are found—the maximum so far found is ten—it is probable that all are killed because the parasite has the habit of leaving one host larva partly consumed and passing on to another if available.

Pupa.—The full-grown grub pupates within the bud, the posterior end of the body being glued to the surface of petals. This keeps the pupa secure in the bud and also helps the adult to extricate itself and emerge from the pupal case. The pupa (Plate XXIII, figs. 5 and 6) is naked and measures about 2 mm. in length and 0·75 mm. in breadth.

The pupal period at 18°C. is eleven to fourteen days, average of eleven observations being twelve days.

Pre-imaginal period.—From the foregoing account, it will be noticed that the pre-imaginal period at 18°C. is about twenty-eight days. Large number of linseed buds containing eggs of the parasite were collected from field during February 1937 and the pre-imaginal period was determined at room temperature. Results are shown in Table I.

TABLE I

Pre-imaginal period of Systasis dasyneurae

Date of collection of eggs	Date of emergence of adult parasites	Pre-imaginal period (Days)	Temperature
4th February 1937 . .	3-8th March 1937 . .	27—32	15°-20°C.
5th February 1937 . .	4-10th March 1937 .	27—33	,,
16th February 1937 .	17-20th March 1937 .	29—32	,,

These results confirm the observations carried out at constant temperature of 18°C.

Detailed description of the adult parasite is given in part II.

3. Seasonal history and incidence

At Pusa the midges (*Dasyneura lini*) first appear in the field in the beginning of January and begin to oviposit soon thereafter. The first generation of the midge is completed in two to three weeks ; thus by the end of March, the pest completes about three generations. The incidence of pest is low in January but increases from the middle of February onwards. At Karnal the winters being more severe than at Pusa, the midges become active a little later. The eggs of the parasite on the other hand were abundant in the fields at Karnal from 4th February onwards.

It will be noticed from the account of the life-history given on the previous pages that the parasite is rather slow in its development, requiring about a month to complete one generation in February, but, because unlike other parasites, it is found in large numbers quite early in the season, it gets a comparatively good start over the host.

On 11th February 1937, 3,565 advanced buds of linseed collected at random from a field at Karnal (Punjab) were kept under observation. Out of these, 254 midges, and 87 parasites emerged. At an approximate rate of three midge-larvae killed per parasite the percentage parasitisation works out as follows :—

Number of larvae killed	=261
Number of larvae emerged as flies	=254
Total .	=515
Percentage parasitisation	=50·7

This is a fairly high parasitisation for such an early time in the season. It must be however noted that this figure gives the percentage of full-grown larvae parasitised and is not based on the total number of larvae, because buds containing or likely to contain younger larval stages of the midge were not collected. Nevertheless, it is evident that the parasite plays an important part in checking the activity of the pest. Observations taken at Sakrand (Sind) and Nagpur (Central Provinces) seem to confirm this view.

II. Description of the parasites

1. Systasis dasyneurae, sp. nov.

Female.—Length about 1·75-2·0 mm. Bright metallic green. Head transverse, nearly three times as wide as long, somewhat wider than thorax, viewed from in front nearly rounded ; frons convex, bright metallic green, densely reticulately sculptured and rugosely punctured, sparsely and finely setose ; vertex rather narrow mesad, with a depression latero-caudad of the lateral ocelli ; ocelli in a slightly curved line, the front one at apex of the antennal foveae and the lateral ones separated from eye borders by a distance

nearly equal to their diameter ; malar space about threefourths the height of eyes ; clypeus truncate mesad and bidentate laterad anteriorly ; left mandible tridentate and the right with an additional very minute denticle between the second and the third teeth ; eyes dark coppery red. Antennae inserted above an imaginary line drawn from the lower borders of eyes ; segments twelve ; scape reaches the front ocellus, dark above and light brown below ; pedicel very dark metallic green above and somewhat dark brown below ; ring joints 2, first transverse, second thicker and slightly wider ; funicle dark brown, with five subequal segments, the first segment about fourfifths the length of pedicel ; club twice the length of pedicel, triarticulate, first segment about one and one fourth shorter than the fifth funicle segment.

Thorax bright metallic green, closely reticulately sculptured ; mesonotum also with scattered larger, coarser, thimble-punctures ; parapsidal furrows complete, deep ; axillae subreticulately sculptured and slightly advanced into the region of the scapulae ; width of scutellum cephalad is about half the length, sculpture reticulate, without cross furrow before apex. Propodium very short and almost hidden by scutellum mesally, expanding laterally, reticulately sculptured ; with well-developed median and lateral carinae ; median carina forking at apex, the forks running along caudal margin but not specially broad ; lateral carinae at apex running strongly mesad along caudal margin and also laterad to the lateral margin but more faintly ; spiracles large, round, situated near cephalic margin in an obscure impression whose caudal margin is faintly carinate.

Fore wings hyaline, about twice as long as broad, veins dark brown ; marginal vein nearly twice the stigmal vein ; postmarginal vein nearly one and one fourth to twice the stigmal ; stigma round ; submarginal vein distinctly broken before and abruptly more slender than the marginal vein ; there are nine long setae in a straight line caudad of and parallel to the marginal vein ; marginal fringes moderately short. Hind wings not specially narrow, their margins not parallel.

Legs : all coxae and hind femora concolourous with thorax ; basal threefourths of fore and mid femora dark coppery brown ; tibiae and tarsi yellowish brown ; terminal tarsal segment brownish.

Abdomen somewhat longer than the rest of body, conic-ovate or ovate, metallic green or bluish-green ; sculpture scaly, with sparse white pubescence denser apically than basally ; ovipositor not exserted.

Male.—Length about 1·5 mm. Except scape below and at base, antennae dark brown ; funicular segments elongated ; first funicular segment distinctly longer than pedicel but equal to the combined lengths of pedicel and the two ring joints ; second segment nearly equal to the first ; third slightly shorter ; fourth equal to third ; fifth a little over threefourths the length of fourth ; club about as long as the two preceding segments combined ; first segment of club nearly as long as the fifth funicular segment. Mesonotum with the umbilicate punctures more sparse than in the female. Propodium moderately broad mesad. Fore wings with stigma relatively larger ; surface pubescence

somewhat finer. Hind wings relatively narrow with margins subparallel. Fore and mid femora, except basal onethird, dirty brown. Hind femur concolourous with thorax. Abdomen about twothirds the rest of body, other characters as in the female.

Holotype.—One female in spirit, in Pusa collection.

Allotype.—One male in spirit, in Pusa collection.

Paratypes.—Several females and males in spirit and on pins, one female and one male mounted on slides, in Pusa collection.

Host.—Dasyneura lini Barnes, second instar larvae.

Coll. T. Ahmad, Karnal (Punjab), Feb.-March, 1937. Also Pusa (Bihar) ; Nagpur (Central Provinces).

This new species resembles *Systasis varipes* Girault [1915] in size, colour, and in the lateral carinae on propodium but differs in the relatively longer postmarginal vein. From *S. insularis* Dodd & Gir. [1915], which it approaches more closely, it is readily distinguished by the differently coloured fore and mid legs and longer postmarginal vein. From *S. henrici* Gir. [1915] it differs in the tridentate mandible.

The genus *Systasis* Walk. [1834], recorded here for the first time from India, comprises fifteen species, cosmopolitan, but mostly described from Australia so far. It belongs to the tribe Tridymariae of the family Miscogasteridae and is easily recognised by twelve-jointed antennae (with two ring-joints) inserted in the middle of face, reticulately sculptured thorax with scattered umbilicate punctures, hyaline wings, marginal vein being twice the stigmal, and by the row of long setae behind marginal vein.

2. *Ecrizotomorpha*, gen. nov.

This new genus is erected for a Pirenine bred from linseed midge along with *Systasis dasyneurae*. It is readily recognised by the pubescent eye, 10-jointed antennae, triarticulate maxillary palpi, long stigmal and postmarginal veins, stout and compressed posterior tibiae and normal second abdominal tergite. From *Herbertia* Howard [1894], which it resembles in the eye pubescence and number of antennal segments, it is easily distinguished by the well-developed stigmal vein and normal second abdominal tergite. From *Ecrizotes* Forster [1861], which it approaches most closely in venation and moniliform antennae of male, it is separated by the pubescent eyes, absence of ring-joints and triarticulate maxillary palpi. It also bears a superficial resemblance to *Spathopus* Ashm. [1904] in its stout and compressed hind tibiae and short stouter fore tibiae but differs in the longer hind tibiae, pubescent eyes, absence of ring-joints and clypeus produced obtusely but not triangularly. It is not likely to be confused with the other genera of the subfamily. In Ferriere's [1934] key this genus runs to couplet number 13, but differs in the funicle having only the first and third segments transverse in female and by the prominent hypopygium and ovipositor.

The following is a full description of the genus :

Non-metallic. Head transverse, thin mesad, narrow at vertex, wider than thorax, rounded in front view. Eyes large, pubescent, not converging above. Clypeus obtusely produced anteriorly. Maxillary palpi triarticulate. Mandibles tetradentate. Antennae short and clavate in female, inserted low down in the face in level with the lower border of eyes ; segments ten; ring-joints absent ; scape long, broad, sub-compressed ; pedicel large, short ; first and third funicular segments transverse and resemble ring-joints ; club triarticulate, terminal segment armed with three spines apically ; in male funicle moniliform, closely pilose, club biarticulate, terminal segment ending in a nipple-like prolongation bearing a long spine. Thorax flat, depressed, finely scaly and with a few scattered setigerous, minute punctures. Fore tibiae stouter and shorter than femora ; in male hind tibiae longer than femora, broad, compressed apically. Wings hyaline ; submarginal in fore wings abruptly slender and broken before uniting with marginal vein ; marginal vein twothirds the submarginal, also twice the well-developed stigmal vein ; postmarginal vein somewhat shorter than stigmal. Parapsidal furrows well developed and deep. Propodium not short mesad, smooth, ecarinate, not produced at apex ; spiracles round and cephalad ; spiracular sulci present. Abdomen in female equal to or somewhat longer than the rest of body, ovate, sessile, second tergite short ; ovipositor and its sheath exerted but not much ; in male variable, compressed and oval or elongate oval and normal, shortly petiolate, second tergite as in female ; hypopygium prominent.

Genotype.—E. taskhiri, sp. nov.

3. Ecrizotomorpha taskhiri, sp. nov.

Female.—Length varies between 0·9-1·5 mm., the average being about 1·25 mm. Black, non-metallic. Head slightly wider than long, thin at vertex and thick near mouth, with a few scattered setigerous punctures ; clypeus slightly metallic blue. Ocelli almost in a line. Scape dark reddish brown, a little over half the length of flagellum ; rest of antenna reddish brown. Pedicel much shorter than club. First funicular segment short, transverse, narrow, trapezoid, resembling a ring joint ; second funicular segment subquadrate, twice the length of first, broader ; third segment like the first ; fourth and fifth subequal to second but wider ; club threefourths the length of scape, much wider than last funicular segment, segments equal ; terminal segment obtusely reduced and broadly rounded apically, with two long, stout, lateral spines and a much longer, slender median spine. Thorax black, scaly, with few scattered punctures or none, but setose. Veins dark brown. Except coxae and femora which are concolourous with thorax, legs light brown ; tibiae slightly darker outside basally ; knee pale.

Male.—Length varies between 1·0-1·5 mm. Black. Pedicel somewhat longer than the first funicular segment. Funicular segments subglobose, except last which is somewhat elongated. First segment of club half the length of club and one and onefourth the last funicular segment. Hind tibiae dark brown. Otherwise as in female.

Holotype.—One female in spirit, in Pusa collection.

Allotype.—One male in spirit, in Pusa Collection.

Paratypes.—Several females and males in spirit and on cards, two females and males mounted on slides ; in Pusa Collection.

Coll. T. Ahmad, Karnal (Punjab), Feb.-March, 1937. Status unknown ; possibly a hyperparasite of *Systasis dasyneurae.*

Summary

Part I deals with the biology and morphology of *Systasis dasyneurae*, a larval parasite of the linseed midge, *Dasyneura lini*. Eggs are laid singly inside unopened flower buds of linseed containing well-developed larvae of the midge, revealing thereby a marked sense of selection on the part of the parasite. The young grub on hatching is fairly hardy and can roam about for over twentyfour hours in search of host larvae. The last four abdominal segments of the grub are very narrow as compared to thorax and the remaining portion of abdomen, and are kept actively moving about to search and feel the host larvae. Before pupation, the grub consumes three to four larvae and this number is usually available in one linseed bud. The full-grown grub pupates within the bud with its posterior end glued to the surface of petals. At 18°C. the egg stage lasts two to three days, the grub stage twelve to fifteen days and the pupal stage eleven to fourteen days. Thus under these conditions one generation is completed in a little less than a month. The parasite seems to play an important part in controlling the pest, as unlike many other parasites it is fairly abundant early in the season. In February 1937 as many as 50·7 per cent of full-grown larvae in buds collected from Karnal (Punjab) were estimated to have been killed by the parasite.

Part II gives the descriptions of *Systasis dasyneurae*, sp. nov. and another Chalcid *Ecrizotomorpha taskhiri*, gen. *et* sp. nov. The exact status of the latter is not known but presumably it is a hyperparasite on the former.

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STUDIES ON THE COCONUT PALM BEETLE (*ORYCTES RHINOCEROS* LINN.) IN SOUTH INDIA

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(With Plate XXIV)

Introduction

Coconut palms in South India are subject to infestation by at least three major pests, *viz.*, the coconut palm beetle (*Oryctes rhinoceros*), the palm weevil (*Rhynchophorous ferrugineus*) and the black-headed caterpillar (*Nephantis serinopa*). Of these, the beetle is most widespread and persistent in all coconut-growing centres in the Madras Presidency and the adjacent states of Cochin, Travancore and Mysore. It is reported to be a serious pest also from other provinces, such as Bombay and Bengal. Outside India, it has been recorded from several countries, such as Burma, Ceylon, Singapore, Sumatra, Java, Celebes, the Philippine Islands, etc.

Several authors have made observations on this insect, *viz.*, Fletcher [1914] and Ramchandra Rao [1930] in South India, Ghosh [1911] in Burma, Hutson [1933] in Ceylon and Mackie [1917] in the Philippine Islands. The beetle has been reported upon also, in the report of the Proceedings of the Second Entomological Meeting, Pusa, by various workers in the different provinces. From a perusal of the literature, it appears that there are variations in the life-history, depending with locality and season where the pest was studied and therefore it is necessary that more data should be collected by further intensive study. During the past three years some interesting observations have been made in the field and the laboratory at Coimbatore and the results thereof are presented hereunder.

Habitat

While the adult beetle spends part or whole of its life in the crowns of trees (coconut, palmyra or Talipot palms), at no other stage it is found in the living tree. The eggs are invariably laid in the heaps of farmyard manure. Occasionally the beetle, eggs and larvae are also found in decaying vegetable matter, such as dead coconut trunks and stumps, decomposing damp choir refuse in coastal tracts, heaps of wet sugarcane trash, and almost any kind of compost in fermenting condition. Invariably, a tree destroyed by the palm weevil disintegrates and becomes easily a veritable breeding ground

for the beetle larvae. But more commonly, the manure pits of dung and trash, when kept undisturbed, serve as a favourite breeding place for the beetle in all the tracts in South India.

Life-cycle and description of immature stages

Egg.—The female beetle burrows into the partly dried-up dung heap and lays its eggs and, under such situations, it is mostly unaccompanied by its male partner. The eggs are laid two to six inches below the surface in semi-wet dung, each egg being deposited individually and covered over with dung material. The egg is almost oval or elliptical in form, measuring 3·1 $\times$2·1 mm. on an average. Before hatching, the creamy white colour changes to yellowish brown and the average size of the now almost spherical egg comes to 4·0$\times$3·4 mm. The egg period varies a good deal taking seven to twenty days as will be seen from the rearing record given below. It is also known from rearings at the Insectary that the eggs laid on the same day, do not all hatch within the same interval and that a number of eggs in each lot fail to hatch due to natural causes.

Table I

*Observations on the duration of the egg period**

Month	Number of days			Remarks
	Minimum	Maximum	Average	
1936				
May	7	14	9·24	25 eggs examined under field conditions.
June	8	14	10·00	18 eggs examined under field conditions.
July	13	16	14·50	21 eggs examined under field conditions.
August	9	11	9·75	12 eggs examined under field conditions.
September	7	18	12·81	37 eggs examined under field conditions.
October	15	20	17·36	11 eggs under laboratory conditions.
November	8	11	8·88	11 eggs under field conditions.
December	9	15	11·05	17 eggs under laboratory conditions.
1937				
January	13	13	13·00	6 eggs under laboratory conditions.
February	11	14	12·60	15 eggs under field conditions.
March	9	14	10·43	32 eggs under laboratory conditions.
April	9	13	11·20	20 eggs under field conditions.

* The exact egg period was ascertained by examining the cages daily.

Grub and its habits.—The newly hatched grub measures 5·5 to 6·0 mm. in length and is whitish in colour with a pale brown head. It commences feeding soon after hatching and, in the course of about forty days, attains a size of about 100 mm. by active feeding and growth. Afterwards, there is practically little change in size. The full-grown grub is clumsily heavy and sluggish in its movements and it always seeks refuge deep below the surface layers of breeding material. The grubs are found at a depth of 2-12 inches, in the semi-wet dung cakes. During unusually dry period, with scanty dung material, young grubs perish and older ones attempt to bury themselves in the deeper layers of moist earth. During periods of active feeding, large quantity of dung material and decomposing vegetable matter are ingested and thrown out as conspicuous pellets and castings. The mature grub when handled exudes large quantities of liquid through its mouth, and semi-solid black matter through its anal opening. The grub, preparatory to pupation, spends a good deal of time in probing the substratum to locate a suitable place for cell formation. Invariably, the earthern cell is excavated in the sides of the pit, usually 6-12 inches below surface level or rarely lower down in the bed of the pit where sufficient moisture is available. The grub, by its wriggling movements, smoothens the walls of the oval chamber now formed and the liquid and the faecal matter exuded in small quantities dry up to make a black smooth lining to the cell or chamber. When completed, the ball-like mass of earth or dung shows no opening or hole on the surface. The grub inside remains as such for about a week or more as could be observed from the cells constructed close to the glass sides of the cages under laboratory rearing. The grub inside the cell gradually shrinks in size and the larval skin by its last moult is thrown off in the cell itself. Some grubs do perish in their efforts at cell formation and pupation.

Under natural conditions, the grubs appear to desert the dung long before pupation and burrow into the soil close to the feeding material. In the course of rearing in the Insectary, a few grown-up grubs were placed in a special wooden cage, which was divided into two compartments by a vertical wire-gauze frame across, leaving enough space at the bottom for the passage of the grubs from one chamber to the other. One compartment was filled with earth and the other with dung cakes, and both kept semi-wet. The grubs were all let into the dung chamber, and at the time of pupation it was found that all slowly found their way to the earthern chamber and pupated there, while not one of them pupated in the dung. It is also noted that, in many cases, a number of grubs perish at the time of pupation, if dung only is supplied. In successful cases, with the dung for pupation, the grub

stage was found protracted and by the time pupation takes place, the dung by feeding and drying is almost reduced to the condition of powdery earth. In field pits, normally the grubs move away from the breeding material to the sides and bottom of the pit, and bury themselves in the earth for pupation. In some cases white ants are seen invading the manure pits, and by their activities an admixture of earth with dung is brought about, and a few of the grubs have been found to pupate in this powdery mixture of earth and dung. The presence of wet soil nearby appears to be a favourable condition for successful pupation. The larval period is pretty long and it varies for different lots or for different specimens of the same lot, both under field and laboratory conditions. The wide variations in the larval period, noticed in the course of a few rearings, are recorded in Table II.

TABLE II

Duration of larval period

Month	Minimum in days	Maximum in days	Average in days	Remarks
1936				
May	124	152	133·6	3 rearings
June	98	136	115·3	6 ,,
July	87	102	99·5	2 ,,
September . . .	93	168	134·0	4 ,,
October . . .	182	182	182·0	1 ,,
November . . .	133	150	138·7	4 ,,
December . . .	103	159	126·4	7 ,,
1937				
February . . .	130	139	135·6	3 ,,
March	88	130	116·0	3 ,,

Pupa.—The newly formed pupa is pale brown and partly covered by the larval exuvium. Later, it becomes reddish brown showing the rudiments of the appendages of the adult folded within the pupal skin. In later stages, the pupa acquires a darker brown tint. The pupal skin is thrown off in the cell, and the adult beetle remains inside the cell for over ten days before it

comes out or shows activity. The pupal period, from cocooning to the emergence of the adult from the cell, varies from seventeen to sixty-two days as observed in the following rearings.

TABLE III

Duration of pupal period

Month	Minimum in days	Maximum in days	Average in days	Remarks
1936				
May	17	32	24·6	6 rearings in lab.
	29	29	29·0	1 rearing in field.
June	28	28	28·0	2 rearings in field.
September	31	31	31·0	1 rearing in lab.
	62	62	62·0	1 rearing in field.
October	34	38	36·0	2 rearings in lab.
	21	35	28·5	9 rearings in field.
November	43	43	43·0	1 rearing in field.
December	31	31	31·0	1 rearing in lab.
	25	54	44·4	3 rearings in field.
1937				
January	28	28	28·0	4 rearings in lab.
February	35	35	35·0	1 rearing in lab.

In view of the fact that the period from cocooning to emergence includes also stages of inactive larva as well as inactive adult within the cell, wide variations are inevitable. In a few instances, these different periods inside the cell have been observed by keeping some individuals close to the glass walls of the cage or by making a small opening in cell for examination. Such details of observations are given in Table IV.

TABLE IV

Cell formation	Pupation	Becoming adult	Emergence out of the cell	Actual period as pupa (days)
16th Sept. 1936	26th Sept. 1936	16th Oct. 1936	28th Oct. 1936	20
16th ,,	28th ,,	18th ,,	28th ,,	20
,,	28th ,,	18th ,,	27th ,,	20
,,	28th ,,	22nd ,,	27th ,,	24
5th Oct. 1936	16th Oct. 1936	9th Nov. 1936	18th Nov. 1936	24
5th ,,	16th ,,	9th ,,	16th ,,	24
31st May 1937	12th June 1937	22nd June 1937	30th June 1937	11

If, during early stage of cell formation, the grub is disturbed, grubs have been known to rebuild fresh cells twice and thrice.

Total life-cycle

The total life-cycle in a few typical cases of rearing from egg to adult is given in Table V.

Table V

Duration from egg to adult

Egg laid on	Adult emerged on	Life-cycle in days	Remarks
21st Dec. 1935.	1st June 1936	162	
21st „ „	29th May „	159	
17th Sept. 1936	17th „ 1937	232	
15th Dec. „	27th „ „	163	
15th „ „	12th June „	179	Reared in the laboratory.
2nd Nov. „	17th May „	196	
30th Jan. 1937.	28th July „	179	
10th Feb. „	28th „ „	168	
21st „ „	30th June „	129	
20th May 1936.	22nd Oct. 1936	155	
22nd „ „	6th Nov. „	168	
23rd „ „	23rd „ „	184	
7th June „	6th „ „	152	
8th „ „	6th „ „	151	Reared in the manure pits.
15th July „	30th Dec. „	168	
13th „ „	21st Jan. 1937	192	
20th Aug. „	21st „ „	154	
4th Sept. „	23rd „ „	141	

The temperature and humidity at which the life-history of the beetle was studied are given in Appendix I.

Egg-laying records

Few workers have indicated large scale trials on the egg-laying capacity of the beetle. The paucity of records on the egg-laying habits of the beetle appears to be due to the fact, that many specimens kept in captivity die away without laying eggs. Ghosh [1911] records " several pairs were placed separately but only two females laid eggs ", one laying eight eggs and the other four eggs. Mackie [1917] has indicated only a probable maximum of thirty eggs. At Coimbatore, under laboratory conditions, large number of beetles were reared out and induced to lay eggs in captivity, providing a variety of conditions. Considerable difficulty was experienced, in the initial stages, in giving a proper feed to the beetles in cages. In the course of the trials, it was found, that the beetles in captivity could be fed more successfully with cane stems than anything else. Out of twenty-four attempts, egg-laying was observed in a dozen cases, and the records relating to a few typical cases are given in Table VI. Under field conditions, a fertilised female, that has entered a suitable manure pit for laying eggs, is observed to remain there for a number of days laying a few eggs each day or at intervals. A few observations on the beetle's egg-laying in field pits are shown in Table VII. It will be seen from Table VI that a single female beetle laid as many as 140 eggs which is the maximum number recorded and two beetles collected from the field and kept in captivity in field cages in manure pits laid over 100 eggs each.

Longevity records

The duration of life of the adult is also subject to great variation under varying circumstances. The study of longevity is particularly important in this instance, in view of the direct injury to the palms caused by the adult beetles. The past records on the longevity of the beetle are scanty. Mackie [1917] puts the limit as eighty-five days and other workers do not seem to have paid much attention to the details of this aspect. In the course of rearings in the Insectary at Coimbatore, during the past three years, the longevity was studied in a number of cases and the longevity records with reference to twenty-eight typical cases are shown in Table VIII. It will be seen from the table that (1) one female beetle lived for 293 days, (2) one male lived for 231 days, and (3) in seven other trials the specimens lived for more than 200 days.

TABLE

Egg-laying records under

Serial No.	Date of emergence of pair	Preoviposition period in days	1st batch		2nd batch		3rd batch		4th batch		5th batch		6th batch		7th batch	
			Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs
1	20-9-36 ♂ 21-9-36 ♀	142	10-2-37	7	11-2-37	1	16-3-37	11	17-3-37	1	19-3-37	5	21-3-37	10	25-3-37	16
2	21-9-36 ♂ 20-9-36 ♀	92	21-12-36	12	13-2-37	3	21-3-37	14	25-3-37	12	29-4-37	4	5-6-37	16	7-6-37	7
3	20-9-36 ♂ 16-10-36 ♀	17	1-11-36	17	2-11-36	2										
4	28-10-36 ♂ 28-10-36 ♀	39	5-12-36	3	8-12-36	3										
5	28-10-36 ♂ 28-10-36 ♀	38	4-12-36	2	10-1-37	24	31-1-37	5	16-2-37	6	28-2-37	5	1-3-37	5	3-3-37	12
6	28-10-36 ♂ 5-2-37 ♀	23	28-2-37	10	8-3-37	2	10-3-37	14	12-3-37	14	26-27-3-37	53	29-3-37	8	2-5-37	12
7	17-5-37 ♂ 7-5-37 ♀	25	12-6-37	9	4-7-37	4	10-7-37	13	18-7-37	6	13-8-37	30	16-8-37	19	22-8-37	6
8	17-5-37 ♂ 12-6-37 ♀	29	11-7-37	9	23-7-37	6	15-16-8-37	39								

VI

laboratory conditions

8th batch		9th batch		10th batch		11th batch		12th batch		13th batch		14th batch			
Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of death	Total No. of eggs
														26-4-37 ♂	
31-3-37	16	3-4-37	9	7-4-37	24	8-4-37	18	9-4-37	4	10-4-37	14	13-4-37	4	24-4-37 ♀	140
														10-5-37 ♂	
9-6-37	2	21-6-37	6	27-6-37	15	30-6-37	8							10-7-37 ♀	99
														21-12-36 ♂ escaped.	
														25-1-37 ♀	19
														25-3-37 ♂	
														19-3-37 ♀	6
														15-5-37 ♂	
														31-5-37 ♀	223
12-3-37	1	24-3-37	31	25-3-37	49	10-5-37	40	13-5-37	25	15-5-37	15	31-5-37	3	11-6-37 ♀	2
														18-3-37 ♂	
														17-4-37 ♂	
														13-5-37 ♀	244
3-4-5-37	32	7-8-5-37	53	12-5-37	30	13-5-37	16							12-6-37 ♀	2
														13-9-37 ♂	
														1-9-37 ♀	87
														12-9-37 ♂	
														7-9-37 ♀	54

TABLE

Egg-laying records

Serial No.	Date of capture of female	Eggs at the time of capture.	1st batch		2nd batch		3rd batch		4th batch		5th batch	
			Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs
1	20-5-36 .	36	21-5-36	7	22-5-36	6	23-5-36	6	24-5-36	4	25-5-36	5
2	4-6-36 . .	69	5-6-36	1	7-6-36	9	8-6-36	4	9-6-36	2	11-6-36	4
3	9-7-36 . .	*Nil*	13-7-36	17	14-7-36	5	15-7-36	2				
4	26-8-36 .	24	28-8-36	20	29-8-36	2	4-9-36	45	13-9-36	1	16-9-36	4
5	2-9-36 . .	74	27-9-36	8	1-10-36	3	4-10-36	5	7-10-36	9	11-10-36	4
6	30-10-36 .	*Nil*	15-11-36	1	18-11-36	12	25-11-36	1	26-11-36	1		
7	10-2-37 .	*Nil*	18-19-2-37	10	21-2-37	13						
8	8-4-37 . .	44	14-4-37	17	15-4-37	7	16-4-37	12	25-4-37	2		
9	14-5-37 .	*Nil*	29-5-37	2	21-22-6-37	6						

VII

in manure pits

6th batch		7th batch		8th batch		9th batch		10th batch		Date of death	Total No. of eggs
Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs	Date of egg-laying	No. of eggs		
26-5-36	5	29-5-36	1	30-5-36	2	31-5-36	1	1-6-36	1	4-5-36	94
13-6-36	3									17-6-36	92
										28-7-36	24
17-9-36	8	18-9-36	3	22-9-36	7	23-9-36	1			5-10-36	115
18-11-36	12									27-11-36	115
										29-11-36	15
										3-3-37	23
										10-5-37	82
										24-6-37	8

Table VIII

Longevity records under laboratory rearing

Serial No.	Date of emergence	Date of death	Longevity in days		Remarks
1	9-8-35	25-8-35	Female	16	
2	9-8-35	5-9-35	Male	27	
3	27-3-36	17-4-36	Female	21	
4	27-3-36	20-4-36	,,	24	Reared specimens—kept without feed.
5	27-3-36	22-4-36	,,	26	
6	27-3-36	22-4-36	,,	26	
7	27-3-36	22-4-36	Male	26	
8	27-3-36	4-5-36	,,	38	
9	20-9-36	26-4-37	,,	218	Pair—reared specimens—fed with sugarcane stem and kept in dark chamber.
10	21-9-36	24-4-37	Female	215	
11	21-9-36	10-5-37	Male	231	Reared pair—fed with cane stem—and kept in dark chamber.
12	20-9-36	10-7-37	Female	293	
13	24-9-36	9-5-37	Male	227	Reared pair—fed with cane stem—and kept in dark chamber.
14	24-9-36	21-12-36	Female	88	
15	20-9-36	21-12-36	Male	92	Reared pair—male escaped—kept in wire-gauze cage in the open ; cane fed.
16	16-10-36	25-1-37	Female	101	
17	26-10-36	13-12-36	Male	48	Reared pair—kept in wire gauze cage in the open with dung for egg-laying and Agave plant for feeding.
18	26-10-36	21-12-36	Female	56	
19	26-10-36	12-12-36	,,	47	Reared specimens—cane fed—male escaped—kept in glass jar.
20	26-10-36	1-3-37	Male	126	
21	26-10-36	31-5-37	Female	217	
22	28-10-36	19-3-37	,,	142	Reared specimens—cane fed—in glass jars.
23	28-10-36	25-3-37	Male	148	
24	28-10-36	15-5-37	Male	199	Reared specimens ; cane fed in jars ; male escaped.
25	28-10-36	31-5-37	Female	215	
26	28-10-36	11-6-37	Male	226	
27	28-10-36	17-4-37	Male	171	Reared specimens—cane fed in jars.
28	28-10-36	18-3-37	,,	141	
29	5-2-37	13-5-37	Female	97	
30	5-2-37	12-6-37	Female	127	
31	17-5-37	13-9-37	Male	119	Reared pair—cane fed—kept in glass jar.
32	17-5-37	1-9-37	Female	107	
33	17-5-37	12-9-37	Male	119	Ditto.
34	12-6-37	7-9-37	Female	87	

TABLE VIII—*contd.*

Serial No.	Date of capture	Date of death	Longevity in days	Remarks
35	21-12-36	16-5-37	Female 147	Collection from outside—date of emergence not known kept in dark chamber—cane fed.
36	27-9-36	9-5-37	Female 224	Specimen collected from tree—left without male in jar and cane fed—date of emergence not known.

STUDY OF SEASONAL INCIDENCE

In a plot with sixty-eight young trees the seasonal incidence of the pest has been under observation. The beetles in a dozen trees specifically marked were being examined and systematically hooked out every week, and at the same time in the same area two small manure pits 4 ft. × 4 ft. × 4 ft. were also dug out and kept in suitable condition for the beetles to come and lay eggs. The pits were examined alternately once a week to note the presence of the beetle or eggs in the dung. As the dung got dry fresh dung was added periodically so as to maintain always a suitable semi-wet condition for egg-laying by the beetles. The record of the beetles removed from trees and those along with eggs, if any, from pits, is given in Table IX.

TABLE IX

Incidence of the beetle in field trees and pits

Month	Number of beetles in dozen trees			Beetles, eggs and grubs in pits
	Female	Male	Total	
May 1936	1	..	1	1 female ; eggs *nil.*
June ,,	4	5	9	1 female ; eggs *nil.*
July ,,	5	3	8	*Nil.* *Nil.*
August ,,	3	1	4	2 females ; 1 male ; 24 eggs.
September ,,	3	1	4	1 female ; 74 eggs.
October ,,	6	1	7	*Nil.* *Nil.*
November ,,	7	3	10	1 female ; eggs *nil.*
December ,,	7	3	10	1 female ; 16 eggs.
January 1937	5	1	6	1 female ; eggs *nil.*
February ,,	14	5	19	*Nil.* *Nil.*
March ,,	20	15	35	*Nil.* *Nil.*

TABLE IX—*contd.*

Month	Number of beetles in dozen trees			Beetles, eggs and grubs in pits
	Female	Male	Total	
April 1937 .	31	15	46	1 female ; 44 eggs.
May „ .	13	9	22	*Nil.* *Nil.*
June „ .	2	2	4	*Nil.* *Nil.*
July „ .	5	3	8	3 females ; 1 male ; 173 eggs ; 3 grubs.
August „ .	8	3	11	2 females ; 2 males ; 69 eggs ; 14 grubs.
September „ .	1	2	3	5 females ; 3 males ; 68 eggs ; 10 grubs.
October „ .	5	2	7	
November „ .	14	6	20	
December „ .	14	7	21	2 females ; 1 male ; 163 eggs.
January 1938 .	14	4	18	4 females ; 2 males ; 96 eggs ; 16 grubs.
February „ .	10	8	18	1 female ; 1 male ; 15 eggs ; 10 grubs.
March „ .	12	13	25	3 females ; 2 males ; 135 eggs ; 63 grubs.

It will be seen from the observations during a period of nearly two years that the beetles are active throughout the year and the egg-laying is also known for all the months with few exceptions. Broods overlap without any definite sequence as the beetles are capable of living for a long time and laying eggs intermittently, and as grubs of different stages are noted almost throughout the year. While some of the beetles begin laying eggs earlier, a good number appear to prefer a longer period of active feeding before evincing breeding activity. It is also clear, that beetles visiting trees are more numerous during March and April. The same observations have been borne out by Ramchandra Rao [1930] who mentions that the attack is worst in the dry season from December to May.

NATURE AND EXTENT OF DAMAGE

Unlike many other forms where damage to crops is caused by the larval stages, in this instance, it is the adult insect that works havoc. The beetles after emergence soon find suitable shelter and food in the tender crowns of the coconut trees. Young as well as old trees are visited by these beetles. They actively burrow into living tissue in the topmost tender regions of the stem, getting access through the axils of the leaves, or cutting through the unopened leaves. The beetle holes, about 1 in. in diameter, vary from ½ to 2 ft. in depth. Sometimes the leaf stalk itself is bored through longitudinally. Often the central shoot with one or two unfolded leaves is cut through drilled vertically down and, as a result, the leaves break off when they grow

FIG. 1. Three trees of the same age, one showing stunted growth due to repeated beetle attack

FIG. 2. (*a*) Healthy grub of *Oryctes rhinoceros* ; (*b*) Grub of *O. rhinoceros* affected by green muscardine fungus

up and open out, and bear marks of the beetle damage in a characteristic manner. In the case of the seedlings and small trees at times of beetle abundance, successive growths of central shoots are hampered to the extent of killing the trees or causing a definite setback in their growth, by repeated attacks (Plate XXIV, fig. 1). Mackie [1917] records that about one per cent of the trees are actually killed annually due to the beetle attack in the Philippine Islands. Death to the trees, caused by the unaided efforts of the beetle alone, is rather difficult of verification and computation, as the attacked trees take a long time before they are killed, and during the period other influences are at work. At the Insectary, two coconut seedlings about two years old had been kept under observation inside separate wire-gauze cages wherein beetles had also been liberated. In both cases, in the course of a year the seedlings were completely killed by the beetles. In nature, in view of the fact, that often four to six beetles are noted in a single tree at different axils and that beetles re-infest trees repeatedly in quick succession, substantial damage to foliage and growing stem is caused. In rare cases, the spathes are also attacked, resulting in reduction of nuts. Apart from such direct mechanical injury it is reported that as a result of the beetle damage, rain water collects in the excavations at the top, causing rotting. It is also indicated by Ghosh [1911], Hutson [1933] and others that the fresh wounds caused by the beetles attract to the tree the palm weevil which is capable of breeding in the tree itself. But, in South India, though beetle activity in varying degree of intensity is seen throughout, the weevil is less common. Our observations on the weevil also suggest that the reverse is always true, *i.e.*, a weevil-attacked tree is sooner or later a definite source of attraction to the beetle.

Food plants other than coconut in India

Fletcher [1914] has recorded the pest on palms of various species, American aloes and sugarcane. Ghosh [1923] gives a detailed list of palms infested by the beetle. In South India, the coconut palm is the most attacked, though the palmyra and the Talipot palms are also affected to some extent. Recently, the beetle has been noticed as doing damage to pineapple by E. R. Gopala Menon at Taliparamba. Agave is also another plant attacked by this beetle ; when plenty of palms are available in the neighbourhood this plant is rarely attacked.

Control methods tried

The very fact that various methods have been tried from time to time by various workers suggests that no one method has proved entirely satisfactory or suited for universal application. The following were tried at Coimbatore :—

1. Trial of baits.—Several kinds of baits namely, sweetened mash of oil-cakes—such as groundnut, castor, gingelly, coconut—with molasses, both in semi-solid and liquid conditions and allowed to ferment in earthen pots were tested. The beetles were not found trapped in any of these.

2. Insecticidal trials.—Granulated calcium cyanide was applied in small quantities to the bore holes containing beetles in young coconut trees. The beetles were found killed, but on such trees it produced slight damage by way of scorching or discolouration to the leaves, especially the tender shoots. As such the material is found unsuitable.

3. Use of light traps.—During periods of abundance of the beetles they dash against street lights but they do not seem to be attracted to specific light traps in any number to be of economic value as control.

4. Trap pits.—Removal of beetles and their immature stages from breeding material, such as manure heaps, dead coconut stumps, etc., has been suggested by many. This method is no doubt of some economic value but has its own drawbacks. In a small area, with sixty-eight young trees, there were two trap pits containing dung. The beetles, eggs and larvae, were removed from each of these pits, at intervals of a fortnight systematically. From May 1936 to March 1938, as many as 42 beetles, 877 eggs and 116 grubs were removed, but there was no material reduction in the damage to the trees. due to the influx of beetles from breeding places elsewhere. The destruction of beetle stages in breeding material in trap pits is not likely to confer much protection to individual gardens unless control measures are taken over a large area.

5. Use of beetle rods.—An iron rod, about $2\frac{1}{2}$ ft. long, 3/8 in. thick and with a hook at one end and the other end bent so as to form a ring for gripping serves fairly satisfactorily for easily locating and removing the beetles from holes. In rare cases, the bore holes run across stem or petiole, when the beetle remaining there is not easily dislodged. In such cases, the side fibrous mattings covering the base of petioles have to be disentangled and the leaf base exposed, to reach the beetle which is then hooked out. As a protection against further entry of beetles into the holes, the holes are filled with sand.

Natural enemies

A mite (*Uropoda* sp.) is sometimes found in large numbers infesting the beetle but no beetle was found actually killed by the mite attack. In rare cases, the mites attack the pupal stage and are able to weaken the emerging adult.

Ants in manure pits attack pupae in imperfectly formed cells and bring about casualties to the same. But the greater mortality to larval and pupal forms, appear to be due to causes, such as overcrowding, want of suitable situation for pupation and drying up of the dung.

Crows are fond of preying on the beetle grubs. When the contents of a manure pit are spread out, crows collect in the area in numbers and remove all exposed grubs.

The green muscardine fungus.—Smith [1936] from Ceylon has described the method of controlling the larvae in breeding places by utilising the green muscardine fungus. Hopkins [1927] has reviewed the work of Friederichs in the introduction of natural enemies in Samoa including the green muscardine fungus for the control of the beetle. Though the early introduction

of the fungus in Ceylon was not reported to be a success, it is now recognised in Ceylon as one of the effective means of checking the pest. Through the courtesy of the Department of Agriculture in Ceylon, the fungus culture was got for trials in South India during 1937. It is found that the fungus is easily raised in culture to desired quantities under laboratory conditions. The trials on the activity of the fungus in pots as well as in pits have indicated that (*i*) the fungus is able to fatally attack the larvae and pupae, (*ii*) the eggs are practically unaffected and are able to hatch out in the inoculated material, (*iii*) the adult beetles continue to thrive and lay eggs in the same, (*iv*) the young grubs are also affected but are difficult to be detected when attacked and (*v*) the full-grown grubs show signs of discolouration at the initial stage of attack and later become covered with the growth of the fungus (Plate XXIV, fig. 2). In view, however, of the great powers of flight of the beetles and the variety of situations under which they breed in different localities, the success of the method is limited to the extent to which they breed in dung and the difficulty cited elsewhere in the case of ordinary dung trap pits has to be overcome here too. The viability of the fungus under periods of drought, the maximum period of the longevity of the spores or resting stage, if any, under adverse conditions, and the possibility of the fungus being multiplied in dung, are being studied.

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APPEN

Temperature and humidity records during the

	December 1935	January 1936	February 1936	March 1936	April 1936	May 1936	June 1936	July 1936	August 1936	September 1936	October 1936
Mean maximum temperature in shade (° F.).	84·9	87·8	91·0	94·1	95·5	98·7	85·4	86·1	85·8	89·9	87·7
Mean minimum temperature in shade (° F.).	65·8	64·4	67·9	70·5	72·8	74·8	71·6	71·1	71·2	71·2	70·5
Mean humidity at 8 hours (per cent)	75·1	73·8	75·4	73·4	69·2	71·4	70·4	72·1	73·9	75·5	79·2

DIX

period of study of the coconut palm beetle

November 1936	December 1936	January 1937	February 1937	March 1937	April 1937	May 1937	June 1937	July 1937	August 1937	September 1937	October 1937	November 1937	December 1937
83·9	84·6	86·0	91·2	94·1	93·5	93·7	89·2	85·3	88·7	89·5	86·9	82·2	85·0
69·0	66·8	64·0	68·2	70·8	73·0	73·7	75·8	74·6	71·2	70·8	70·6	69·0	63·9
84·0	76·0	72·8	75·5	70·2	71·5	72·7	68·5	72·0	74·5	72·0	77·4	81·4	74·3

CHROMOSOME NUMBER IN INDIAN LINSEED, *LINUM USITATISSIMUM* L.

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(With Plate XXV)

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I. Introduction

The Indian linseed, *Linum usitatissimum* L., has been investigated especially from economic points of view by several workers in India [Howard, Howard and Khan 1910, 1920 ; Graham and Roy, 1924 ; Howard and Khan, 1924 ; Shaw, Khan and Alam, 1931 ; Deshpande and Mallik, 1937 ; Kadam, Kulkarni and Patel, 1938]. Cytologically the varieties have not so far been studied in this country. The present paper deals with the somatic and meiotic chromosomes of some varieties grown in the Central Provinces and Berar.

The diploid chromosome number in the varieties of *Linum usitatissimum* examined in other countries by Reynders [1926]*, Kikuchi [1926]*, A. Nikolajewa [Emme and Schepeljeva, 1927]* was found to be thirty and haploid number by Vilmorin and Simonet [1927]* and Kikuchi to be fifteen. But Emme and Schepeljeva record thirty-two as the diploid number in a great number of different varieties of this species and thirty in only one variety. Martzenitzina [1927]* also records thirty-two as the diploid number in this species.

* These references have been taken from " Tammes [1928], who has reviewed the literature on the genetics of the genus *Linum*.

The chromosomes on the whole are very short and to some extent they show among themselves some morphological variations, such as the size (large and short) and shape (rod-like and bent). The various shapes are probably due to the different positions of the attachment constrictions (Plate XXV, fig. 2).

2. No. 3243 (E B 3 × Punjab linseed)

Thirty chromosomes are distinctly observed. The plates invariably showed two nucleolar fragments. The circular shape of the fragments and their positions at slightly different levels from the mitotic plate help in isolating them from the small types of chromosomes. The plate (Plate XXV, fig. 1) shows distinctly most of the homologous chromosomes lying more or less in parallel positions.

3. No. 117 (Selection)

$2n=30$ chromosomes were distinctly observed. Only one nucleolar fragment at different focus was seen (Plate XXV, fig. 3), which was always found lying very close to one of the chromosomes.

4. Local-Balaghat (Waraseoni Red)

It showed $2n=30$ with occasional one or two nucleolar fragments which sometimes are found associated with chromosomes.

5. E B 3 (Selection)

It showed $2n=30$ with one nucleolar fragment. The latter was always seen at a different level.

6. No. 3255 (E. B. 3 × Punjab linseed)

$2n=30$, with one or two nucleolar fragments, are distinctly observed. The latter are the circular bodies situated at different levels.

Morphologically the chromosomes in each set can be distinguished into three distinct types.

1. Long and rod-like chromosomes.
2. Short and rod-like chromosomes.
3. Bent chromosomes.

Further morphological distinction is difficult.

IV. Observations on meiotic chromosomes

Meiotic chromosomes were examined from the permanent smear preparations at late diakinesis, I metaphase and II metaphase.

At late diakinesis fifteen bivalents were seen all scattered at different levels (Plate XXV, fig. 4). On account of deep staining it was not possible to see distinctly the chiasmata in the bivalents. No nucleolar material is detected. The nuclear wall completely disappears at this stage.

At I metaphase fifteen bivalents are distinctly seen in polar view (Plate XXV, figs. 5 and 7). Nucleolar material is not observed. Secondary associations are formed at this stage (Plate XXV, figs. 5 and 7, 8) suggesting thereby that linseed is a secondarily balanced polyploid. Plate XXV, fig. 6 probably represents a stage in between the pro-metaphase and metaphase.

At II metaphase fifteen univalents are observed (Plate XXV, fig. 8).

V. Summary

The somatic and meiotic chromosomes of Indian linseed, *Linum usitatissimum* L., grown in the Central Provinces and Berar were examined. The diploid chromosome number is found to be thirty in root-tip cells.

At late diakinesis and I metaphase fifteen bivalents and at II metaphase fifteen univalents are observed.

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COMPARISON OF DIFFERENT METHODS OF COMPOSTING WASTE MATERIALS*

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WORK has been proceeding at the Indian Institute of Science for some time past on a comparison of different methods of composting town and farm wastes. Special attention was paid to the ' hot ' fermentation method, wherein compost material was kept aerobic for a preliminary period of five to six days, during which time, there was rapid decomposition and rise of temperature to 65-70°C. At the end of the above period, the mass was covered over with a layer of mud paste and over it earth and kept closed for about $2\frac{1}{2}$ to 3 months, to allow anaerobic rotting to take place. The manure was then ready for application to land. The hot fermentation method was compared with the aerobic methods in ordinary use in this country, *e.g.*, decomposition in shallow wide trenches and in heaps overground.

The following procedures of composting were compared using one ton lots of compost material.

1. Hot fermentation in underground trenches which were brick-lined and plastered.

2. Hot fermentation in underground trenches without brick-lining.

3. Hot fermentation method in heaps overground on brick-lined platforms.

4. Hot fermentation method in heaps overground on platforms which were not brick-lined.

5. Aerobic process in shallow wide trenches which were not brick-lined.

6. Aerobic process in heaps overground on platforms which were not brick-lined.

The quantities of materials taken and the methods of mixing were the same for the hot fermentation and aerobic methods. The hot fermented composts, however, were packed air-free after five or six days as described above, whereas the ' aerobic ' composts were turned over once a fortnight and watered if necessary.

Two different starters were tried, *viz.*, night soil and urine-dung mixture. Each trial was carried out in duplicate.

*Contribution to the Discussion on " Composts " held by the Indian Science Congress, at Lahore in January 1939.

In the first series using night soil as starter, the relative proportions of the constituents taken were 1000 lb. of screened leaves and other organic fractions of street sweepings, 500 lb. of the screened soil fraction of street sweepings and 1000 lb. of night-soil (fresh). These were mixed in aliquot portions at a time within the container itself, where the compost was to be kept. The moisture level was brought to about 50 per cent by the addition of seventy gallons of water, which were added to the night-soil in portions, so as to facilitate uniform mixing of the street sweepings with night-soil. The mixing operations were generally carried out with forks.

In the second series, where urine-dung mixture was used as the starter, an emulsion of dung and urine was prepared by the addition of 200 lb. of dung to twenty-five gallons of cattle urine, and out of this emulsion, five gallons (by volume) were uniformly mixed with every lot of 100 lb. of leaves and 50 lb. of soil fraction. Further water to the extent of four to five gallons were added. The mixing was done within the container itself in small lots of the above order, which were continued till a total weight of 1000 lb. of leaves and 500 lb. of soil had been taken.

All the manures were removed after three months, and weighed. Samples were taken for analysis and the main bulk was stored in covered cisterns till required for pot and plot experiments.

The refuse materials used for composting had the following average composition :—

Composition of refuse materials

(*All figures are on fresh basis including moisture*)

	Street-sweepings screened into		Night soil (fresh)
	Soil fraction (per cent)	Leaves fraction (per cent)	(per cent)
1. Total carbon	3·07	30·71	9·30
2. Total nitrogen	0·24	1·23	1·10
3. Ash-free organic matter	6·20	54·30	15·30
4. Ash	91·30	36·10	4·20
5. Moisture	2·50	9·60	80·50

The analytical data obtained are presented in Tables I and II, the former referring to the experiments with night soil and the latter to those where urine plus dung was used as the starter.

TABLE I

Semi-large scale experiments using night soil as starter

Taken 1000 lb. leaf material 500 lb. soil fraction of town refuse 1000 lb. night soil (fresh)	Yield of manure		Carbon		Nitrogen		Ash-free organic matter	
	Fresh lb.	Sun-dried lb.	Per cent analysis	Per cent recovery	Per cent analysis	Per cent recovery	Per cent analysis	Per cent recovery
I. Hot fermentation in underground Trenches with brick-lining.	3,215	1,520	19·81	72·46	1·22	75·91	34·93	73·05
II. Hot fermentation in underground trenches without brick-lining .	3,010	1,438	18·01	62·34	1·13	66·36	31·85	63·01
III. Hot fermentation in heaps overground on brick-lined platforms.	2,760	1,325	17·84	56·90	1·19	64·34	30·39	55·39
IV. Hot fermentation in heaps overground on platforms not brick-lined.	2,620	1,280	17·05	52·53	1·10	57·58	29·55	52·02
V. Aerobic, in shallow wide trenches	2,230	1,185	16·60	47·36	1·08	52·49	29·36	47·87
VI. Aerobic in heaps overground .	1,980	1,042	14·98	37·58	0·99	42·09	28·89	41·41

TABLE II

Semi-large scale experiments using cattle urine and dung as starters

Taken 1,000 lb. leaf material, 500 lb. soil, 50 gallons of urine-dung mixture	Yield of manure		Carbon		Nitrogen		Ash-free organic matter	
	Fresh	Sun-dried	Per cent analysis	Per cent recovery	Per cent analysis	Per cent recovery	Per cent analysis	Per cent recovery
	lb.	lb.						
I. Hot fermentation in underground trenches with brick-lining.	3,015	1,415	17·81	77·45	0·77	79·52	31·11	75·88
II. Hot fermentation in underground trenches without brick-lining.	2,784	1,320	17·04	69·15	0·74	71·53	28·78	65·52
III. Hot fermentation in heaps overground on brick-lined paltforms.	2,645	1,275	16·47	64·54	0·69	64·12	26·27	57·76
IV. Hot fermentation in heaps overground on platforms not brick-lined.	2,496	1,190	15·13	55·32	0·63	54·75	25·66	52·64
V. Aerobic, in shallow wide trenches	2,112	1,075	13·95	46·10	0·60	47·10	24·82	46·03
VI. Aerobic, in heaps overground .	1,826	960	13·02	38·41	0·59	41·35	23·44	38·80

The data clearly confirm the superiority of the hot fermentation process over the aerobic methods, as shown by the higher conservation of carbon, nitrogen and of ash-free organic matter.

Considering first the experiments with night soil, recoveries of carbon, nitrogen and ash-free organic matter as high as 72-76 per cent can be obtained by adopting the hot fermentation principle in trenches which are brick-lined and plastered. The recovery, however, falls to about 62-66 per cent when the trenches are not brick-lined and plastered, due probably to seepage losses. In heaps overground on brick-lined platforms which are closed by a layer of earth after the first week (*vide* treatment III) the recovery obtained is of the

order 57-64 per cent and in the heaps overground on platforms which are not brick-lined but which are similarly closed after the first six days, according to the hot fermentation principle (*vide* treatment IV), the recovery is about 52-57 per cent. The recoveries are lowest in the aerobic methods, whether conducted in shallow trenches or in heaps overground. The conservation is rather better in the former case, being about 47-52 per cent, as compared with about 40 per cent recovery in the latter case.

A similar picture is shown by the data relating to experiments where urine plus dung was used as the starter. The recoveries of carbon, nitrogen and of ash-free organic matter are particularly good in the case of the hot fermentation methods, being of the order of 65 to 80 per cent, while the aerobic methods show a recovery of only 38-47 per cent.

The low recoveries in the aerobic processes are, no doubt, due to the more vigorous oxidation and decomposition of the constituents due to turning the mass over at intervals, accompanied by watering. It is no doubt true that for the preparation of satisfactory compost there should be an appreciable amount of oxidation and biological decomposition of the organic refuse. Such preliminary decomposition serves to remove the more easily oxidisable constituents which, otherwise, may later retard nitrification when applied to the soil. But it is quite possible that the degree of preliminary oxidation may be accentuated in some of the aerobic methods now in use and the biological decomposition prolonged to such an extent that even the less easily oxidisable constituents such as the cellulose-xylan complexes and ligno-cellulose may be attacked. These complexes, on account of their slow rate of decomposition, will not interfere with nitrification in the soil, but may, on the other hand, help to increase the amount of soil organic matter. Certainly, a stoppage of the aerobic type of decomposition, at an earlier stage, means a proportionately greater recovery of manure.

But in addition to stopping the aerobic decomposition at an earlier stage, the hot fermentation method requires the maturing of the manure under anaerobic conditions for $2\frac{1}{2}$ to 3 months, during which period the material undergoes further degradation and humification, and its nitrogenous compounds are rendered more easily available for nitrification.

In this connection, it may be mentioned that there is a strong school of opinion who doubt the wisdom of composting refuse materials with nitrogenous starters and enquire whether a similar benefit may not be obtained by an application of the refuse material directly on to land, along with the amount of nitrogenous starter required to successfully compost it. Experiments on these lines have been recently started at Rothamsted [1935, 1936, 1937], but the results obtained, so far, are of a preliminary and conflicting nature. Eden [1937] has also started in Ceylon a series of experiments to compare the effect of the application of prunings and other tea garden wastes directly on to the land carrying the crop, instead of previously composting the same before application. These experiments also have only recently been begun and have not yielded so far any definite results.

The above school of thought lay emphasis on a suitable C : N ratio in the refuse material added to the land, rather than on the chemical make-up of such material. One of the striking features of composting is the alteration in chemical make-up of the organic wastes, by way of removal of the readily oxidisable constituents, in addition to the shifting of the C : N ratio into a more optimum range for crop production. The results of the above experiments carried out at Rothamsted and in Ceylon, if continued for a decade or more, will no doubt, help in differentiating between the beneficial effects due to such alteration in chemical make-up brought about by composting and those due to the presence of an optimum C : N ratio. Interesting results may be obtained if experiments on similar lines could be conducted in this country, since the climatic and soil conditions here vary greatly from those in England, and the Ceylon experiments are confined only to tea estate wastes, which have a narrow C : N ratio (about 12 : 1).

The hot fermentation method strikes a *via media* between the above school of thought and the followers of the older school of aerobic composting, in that the readily oxidisable constituents are removed, in the hot fermentation system, during the preliminary period of aerobic decomposition and, further, the availability of nitrogen is increased by the higher percentage of nitrogen secured in the final compost. Plot experiments in the field and nitrification studies in the laboratory, to be described below, have shown that the hot fermented manure is equal in quality and, in many trials, superior to the aerobically prepared manure.

Nitrification studies in the laboratory

As typical representatives of the three methods of composting, the hot fermented compost in trenches, the aerobically prepared manure in shallow trenches and the material which was anaerobically packed from the start, were taken for nitrification studies in the laboratory. Two grm. portions of the fresh manure were added to 100 grm. portions of a garden soil from Bangalore, in wide-necked bottles, mixed well and enough water was added to bring the moisture content to 50 per cent of the water-holding capacity. The bottles were weighed and every alternate day the requisite amount of water was added to bring back the moisture content to the initial level.

At the end of 4, 6, 8, 12 and 16 weeks, duplicate bottles for each treatment were removed, the contents were air-dried, weighed, and aliquots were taken for the determination of (*a*) ammoniacal nitrogen (*b*) total nitrogen and (*c*) nitrate nitrogen. As the figures for total nitrogen and ammoniacal nitrogen

did not show any striking variations between the different treatments, only the data for nitrate nitrogen are presented in Table III.

TABLE III

Nitrification experiments in the Laboratory

Nature of manure (added 2 grms. fresh manure to 100 grms. graden soil)	Mg. of NO_3-N present per 100 grms. of soil after incubation for				
	4 weeks	6 weeks	8 weeks	12 weeks	16 weeks
1. Hot fermentation in underground trenches	4·52	5·05	5·59	6·38	6·92
2. Aerobic process in shallow wide trenches	3·72	3·99	4·52	5·05	5·32
3. Anaerobic packing from the start .	3·46	3·72	4·52	5·32	5·85

The figures show that the hot fermented compost nitrifies at a more rapid rate than the aerobically prepared manure ; this is partly due to the high content of nitrogen in the former manure. It is interesting to note that the initial rate of nitrification of the material preserved anaerobically from the start is lower than that of the other two. This is probably due to the fact that such anaerobically kept material contains a good amount of the easily oxidisable fraction which retards nitrification in the soil. In the hot fermentation method, such easily oxidisable fractions are removed during the preliminary aerobic treatment.

Plot experiments

Plot experiments were carried out to determine the manurial value of the night soil composts prepared by the different methods. The amounts of the different manures corresponding to oven-dry weights of 20 lbs. were added to plots 10 ft. × 10 ft. in random arrangement. The crops tried were *ragi* (*Eleucine coracana*) in the first season and *jowar* (*Sorghum vulgare*) for residual effect in the succeeding season. The soil used was a sandy loam, rather poor in nitrogen and phosphorus.

The crop yields obtained are given in Table IV. They again demonstrate the superior manurial value of the hot fermented composts over others. This superiority is no doubt due to the better conservation of nitrogen secured in the hot fermentation method.

TABLE IV

Results of plot experiments with composts—7×7 Latin Square
(ragi *in the first season and* jowar *in the next season for residual effect*)

Treatment (composts prepared from night soil and town refuse)	*Ragi* (*Eleucine coracna*)				*Jowar* (*Sorghum vulgare*) fodder (dry wt.)	
	Grain		Straw		Totals of 7 plots	Yield per acre
	Totals of 7 plots	Yield per acre	Totals of 7 plots	Yield per acre		
	lb.	lb.	lb.	lb.	lb.	Tons
I. Hot fermentation in underground trenches brick-lined and plastered . .	43·0	2,676	93·8	5,837	441	12·26
II. Hot fermentation in underground trenches without bricklining . .	38·8	2,414	88·2	5,489	392	10·89
III. Hot fermentation in overground heaps plastered over with mud . .	36·7	2,284	86·1	5,358	354	9·84
IV. Aerobic method in shallow wide trenches . .	32·2	2,004	80·5	5,009	322	8·95
V. Aerobic method in heaps overground . . .	30·1	1,874	75·6	4,704	294	8·17
VI. Ammonium sulphate of equivalent nitrogen content	27·3	1,699	71·7	4,462	210	5·83
VII. Control plots—no manure	18·2	1,133	44·1	2,745	161	4·47
Mean yield of treatments .	32·3	2,012	77·1	4,801	311	8·64
Standard deviation .	1·49	92·7	2·33	145	16·27	0·45

The work described above was carried out as part of a scheme of investigation on composting methods carried out at this Institute with the financial assistance of the Imperial Council of Agricultural Research. The writer wishes to acknowledge help received from Mr. C. Parthasarathy in carrying out the nitrification studies in the laboratory.

Summary

A comparison of different methods of composting town and farm wastes, as judged by plot trials in the field and by nitrification experiments in the laboratory, showed the superiority of the ' hot ' fermentation process over the usual aerobic methods. The former gave a higher recovery of organic matter and of nitrogen than the latter (about $1\frac{1}{2}$ times) and the resulting manure was equally efficient in crop production and in several cases superior. Starting from the same amount of original materials, it is possible, by suitable dilution with soil, to obtain by the hot fermentation process about $1\frac{1}{2}$ times as much manure as is obtained by the usual aerobic methods and containing the same percentages of carbon and of nitrogen. Indications were obtained during the course of the work that the rationale of composting waste materials needs a re-examination. The satisfactory behaviour of the hot fermented composts in the field would go to show that in the aerobic methods, as usually adopted, the oxidation is carried to an extreme stage when even the less oxidisable fractions are attacked and thus avoidable losses of dry matter and of nitrogen occur. The recent experiments at Rothamsted and in Ceylon on composts *versus* uncomposted material are also discussed.

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REVIEWS

Science in Africa. By E. B. Worthington : Oxford University Press, London, New York, Toronto ; 1938. Pp. XVI & 746. Price 10*s*. 6*d*.

This book is one of the issues of the African Research Survey conducted under the guidance of Lord Hailey with the object of exploring further possibilities for the development of the continent. The author had the privilege of joining Lord Hailey during the latter part of the tour and thus acquainting himself with the conditions prevailing there in addition to his previous experience gained in East Africa from his work in connection with the Great Lakes.

In this book, Dr. Worthington deals in a thorough manner with the present organisation and results achieved in different branches of science and gives the reader a comprehensive picture of the position attained and progress made in the various subjects.

It is difficult to find oneself in full agreement with all that is written ; page 421 being an example of the repetition of a superstition which was easily exploded in India though tenaciously held by the earlier workers. It is also difficult to visualise the potentialities of the beef breed aimed at—if the Hereford, Angus and Dexter-Kerry are all regarded—as equally suitable crosses. Plate VII is remarkable both for the straightness of the work and the curious method of training adopted. A double mould board being to say the least a curious implement for training purposes, but taking it by and large a variety of subjects are dealt with in considerable detail and the book forms an interesting addition to our knowledge of Africa. [W. S.]

International Bibliography of Agricultural Economics. (Quarterly publication of the International Institute of Agriculture, Rome).

The International Institute of Agriculture in Rome has now begun to publish a current bibliography, at quarterly intervals, which deals with agricultural economics in all its various phases. The first issue of October 1938 has just been printed.

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NOTICE

The Indian Journal of Agricultural Science

A Bi-monthly Scientific Journal of Agriculture and the Allied Sciences, mainly devoted to the publication of the results of original research and field experiments

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